This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

Digitized by Google

RR.w.534 (1)

B.185.f.20

C

E.BIBL.RADCL.

Z
C.4
B

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Miscellanea Curiosa.

BEING A

COLLECTION

Of some of the Principal

PHÆNOMENA

IN

NATURE,

Accounted for by the Greatest Philosophers of this Age.

TOGETHER

With several DISCOURSES read before the ROYAL SOCIETY, for the Advancement of Physical and Mathematical Knowledge.

LONDON:

Printed by *J. B.* for *Jeffery Wale*, at the *Angel* in St. *Paul's* Church-yard; and *John Senex*, in *Hemlock-Court*, near *Temple-Bar*, 1705.

Digitized by Google

A COLLECTION

Chiefly the Principal

PHENOMENA

IN

NATURE.

Digitized by Google

TO THE

READER.

SOME of the Principal Discoveries and Enquiries, both in *Physical* and *Mathematical* Learning, being regiſter'd in the Voluminous Journals of the *Royal Society*, are amongſt a multitude of leſs uſeful Matters, ſo Obſcurely hid, that but very few inquiſitive Gentlemen ever ſo much as heard of them.

The Deſign therefore of the enſuing Collection, is to digeſt in a convenient Method, all the moſt curious *Philoſophical* and *Mathematical* Diſcoveries, as they are to be met with, which may any way tend to the Uſe of Life, or Advancement of Arts and Sciences.

Digitized by Google

And on this Occasion, it will be convenient to intimate to the Reader;

First, That the Theories and Discourses here collected, have already past the Censure of the *Learned World*: Who have acknowleg'd them the most satisfactory Accounts of Nature's Proceedings, wherein some of her greatest Depths are fathom'd, and a Foundation laid for Posterity to build an infinite *Superstructure*.

Secondly, That they are related (*Verbatim*) just as they were delivered in, or read before the *Royal Society*: For it has been the Opinion of the most Judicious amongst those *Honourable Members*, that it is impossible so to abridge them, (which are but Abridgments themselves) as not to render them obscure and unintelligible.

Digitized by Google

A TABLE OF THE *Discourses* contained in this *Volume.*

Pag.

AN *Estimate of the Quantity of* Vapours *raised out of the Sea, as derived from Experiment: Together with an Account of the* Circulation *of the wat'ry Vapours of the Sea, and of the Cause of* Springs. *Presented to the Royal Society by Mr.* E. Halley, *F.R.S.* 1

The True Theory of the Tides, *extracted from that admired Treatise of Mr.* Isaac Newton, *Intituled,* Philosophiæ Naturalis Principia Mathematica; *being a Discourse presented with that Book to the late King* James, *by Mr.* E. Halley. 13

A Theory of the Variation *of the* Magnetical Compass, *by Mr.* E. Halley. 27

An Account of the Cause of the Change of the Variation *of the* Magnetical Needle, *with an Hypothesis of the Structure of the* Internal Parts

Digitized by Google

Page

Parts *of the* Earth; *as it was presented to the Royal Society in one of their late Meetings, by Mr.* E. Halley. 43

An Historical Account of the Trade-Winds *and* Monsoons, *observable in the Seas between and near the* Tropicks; *with an Attempt to assign the Physical Cause of the said Winds, by Mr.* E. Halley. 61

A Discourse of the Rate of the Decrease of the Heights of the Mercury *in the* Barometer, *according as Places are elevated above the Surface of the* Earth; *with an Attempt to discover the true Reason of the rising and falling of the* Mercury, *upon Change of Weather, by Mr.* E. Halley. 81

A Letter from Mr. Isaac Newton, *while Professor of the Mathematicks in the University of* Cambridge; *containing his new* Theory *about* Light *and* Colours: *Sent from* Cambridge, Feb. 6. 167½. *in order to be communicated to the Royal Society.* 97

A farther Explanation of the same Theory. 115

A Demonstration concerning the Motion of Light, *communicated from* Paris. 118

An Introductory Essay to the Doctrine of Sounds, *containing some Proposals for the Improvement of* Acousticks; *as it was presented to the* Dubling *Society by the Right Reverend Father in God* Narcissus, *Lord Bishop of* Ferns *and* Leighlin. 121

A Discourse concerning the Modern Theory *of* Generation, *by Dr.* Geo. Garden, *of* Aberdeen, *being part of a Letter to Dr.* William Musgrave, *D. L. D. Reg. Soc. S. and by him communicated to the Royal Society.* 142

A

The TABLE.

Page

A short Discourse concerning Concoction: *Read at a Meeting of the* Royal Society, *by* Clopton Havers, *M. D. Fellow of the Royal Society.* 155

A Discourse concerning some Influence of Respiration *on the Motion of the* Heart *hitherto unobserved. By* J. Drake, *M. D. F. R. S.* 173

Some Thoughts and Experiments concerning Vegetation. *By* John Woodward, *M. D. of the College of Physicians and Royal Society, and Professor of Physick in* Gresham-College. 205

An Account of the Measure of Gold *upon Gilt Wire; together with a Demonstration of the exceeding Minuteness of the* Atoms, *or constituent Parts of* Gold; *as it was read before the* Royal Society, *by Mr.* E. Halley. 245

An Account of Dr. Robert Hook's *Invention of the* Marine Barometer, *with its Description and Uses. Published by Order of the Royal Society by Mr.* E. Halley. 252

A Discourse concerning the Proportional Heat *of the Sun in all* Latitudes; *with the Method of collecting the same, as it was read before the* Royal Society *in one of their late Meetings, by* Mr. E. Halley. 258

Concerning the Distance of the Fixed Stars, *by the Honourable* Fran. Roberts, *Esq; F. R. S.* 277

Mr. Isaac Newton's *Theory of the* Moon. 270

An Estimate of the Degrees of the Mortality of Mankind, *drawn from Curious Tables of* Births *and* Funerals *at the City of* Breslaw; *with an Attempt to ascertain the* Price of Annuities *upon Lives, by Mr.* E. Halley. 282

Digitized by Google

The TABLE:

Page

A Diſcourſe concerning Gravity, *and its Properties, wherein the Deſcent of* Heavy Bodies, *and the Motion of* Projects *is briefly, but fully handled: Together with the Solution of a Problem of great Uſe in* Gunnery, *by Mr.* E. Halley. 304

A Propoſition of General Uſe in the Art of Gunnery, *ſhewing the Rule of laying a* Mortar *to paſs, in order to ſtrike any Object above or below the Horizon, by Mr.* E. Halley. 326

A Diſcourſe concerning the Meaſure of the Air's Reſiſtance to Bodies moved in it. By the Learned John Wallis, *S. T. D. and F. R. S.* 334

An Inſtance of the Excellency of the Modern Algebra, *in the Reſolution of the Problem of finding the* Foci *of Optick Glaſſes univerſally. By Mr.* E. Halley, *S. R. S.* 350

Corrections made by Mr. *Iſaac Newton* to the *Theory* of the *Moon.*

PAGE 270. l. 19. r. *ſhall ſcarce be above two Minutes in her Syzygys, or above three in her Quadratures.* p. 271. l. 19. f. 39 *min.* r. 45 *min.* ib. l. 27. f. 247, r. 267. ib. l. ult. f. 0 *ſec.* r. 40 *ſec.* p. 272. l. 5. f. 247 r. 267. p. 274. l. 32, 33, f. *compared* r. *computed.*

P. 328. l. 15. f. *by* r. *but.* p. 329. l. 23. f. $\sqrt{+}$ *bb bb* or. $\sqrt{bb+bb}$.

Miſcellanea Curioſa.

An Eſtimate of the Quantity of Vapours raiſed out of the Sea, derived from Experiment: Together with an Account of the Circulation of the watry Vapours of the Sea, and of the Cauſe of Springs, preſented to the Royal Society,

By Mr. E. Halley, F. R. S.

THAT the Quantity of Aqueous Vapours contain'd in the Medium of the Air, is very conſiderable, ſeems moſt evident from the great Rains and Snows which are ſometimes obſerv'd to fall, to that degree, that the Water thus diſcharg'd out of the Interſtices of the Particles of Air, is in weight a very ſenſible part of the incumbent Atmoſphere: But in what proportion theſe Vapours riſe, which are the Sources not only of Rains, but alſo of Springs or Fountains (as I deſign to prove) has not, that I know of, been any where well examin'd, tho' it ſeem to be one of the moſt neceſſary Ingredients of a Real and Philoſophical Meteorology, and as ſuch to deſerve the Conſideration of this Ho-

Digitized by Google

nourable Society. I thought it might not be unacceptable to attempt by Experiment to determine the Quantity of the Evaporations of Water, as far as they arise from Heat, which upon Trial succeeded as follows.

We took a Pan of Water, about 4 Inches deep, and 7 Inches $\frac{2}{10}$ Diameter, in which we placed a Thermometer, and by means of a Pan of Coals, we brought the Water to the same degree of Heat, which is observed to be that of the Air in our hottest Summer; the Thermometer nicely shewing it: This done, we affixed the Pan of Water, with the Thermometer in it, to one end of the Beam of a Pair of Scales, and exactly counterpois'd it with weights in the other Scale; and by the application or removal of the Pan of Coals, we found it very easie to maintain the Water in the same degree of Heat precisely. Doing thus we found the weight of the Water sensibly to decrease; and at the end of two hours we observed that there wanted half an ounce *Troy*, all but 7 grains, or 233 grains of Water, which in that time had gone off in Vapour; tho' one could hardly perceive it smoke, and the Water were not sensibly warm. This Quantity in so short a time seemed very considerable, being little less than 6 ounces in 24 hours, from so small a Surface as a Circle of 8 Inches Diameter. To reduce this Experiment to an exact Calculus, and determine the thickness of the Skin of Water that had so evaporated, I assume the Experiment alledged by Dr. *Edward Bernard* to have been made in the *Oxford* Society, *viz.* That the Cube-foot English of Water weighs exactly 76 Pounds *Troy*; this divided by 1728, the number of Inches in a Foot, will give 253$\frac{1}{3}$ grains or $\frac{1}{2}$ ounce

ounce $13\frac{1}{3}$ grains for the weight of a Cube-inch of Water; wherefore the weight of 233 grains is $\frac{233}{13\frac{1}{3}}$ or 35 Parts of 38 of a Cube-inch of Water. Now the Area of the Circle whose Diameter is $7\frac{9}{10}$ Inches, is 49 square Inches; by which dividing the Quantity of Water evaporated, *viz.* $\frac{35}{38}$ of an Inch, the Quote $\frac{35}{1862}$ or $\frac{1}{53}$ shews that the thickness of the Water evaporated was the 53d part of an Inch; but we will suppose it only the 60th part, for the Facility of Calculation. If therefore Water as warm as the Air in Summer, exhales the thickness of a 60th part of an Inch in two hours from its whole Surface, in 12 hours it will exhale the $\frac{1}{10}$ of an Inch; which Quantity will be found abundantly sufficient to serve for all the Rains, Springs, and Dews; and acount for the *Caspian* Sea, being always at a stand, neither wasting nor overflowing; as likewise for the Current said to set always in at the Streights of *Gibralter*, tho' those Mediterranean Seas receive so many and so considerable Rivers.

To estimate the Quantity of Water arising in Vapours out of the Sea, I think I ought to consider it only for the time the Sun is up, for that the Dews return in the night, as much if not more Vapours than are then emitted; and in Summer the Days being longer than 12 hours, this Excess is ballanced by the weaker Action of the Sun, especially when rising before the Water be warmed: So that if I allow $\frac{1}{10}$ of an Inch of the Surface of the Sea, to be raised *per diem* in Vapours, it may not be an improbable Conjecture.

Upon this Supposition, every 10 square Inches of the Surface of the Water, yields in Vapour *per diem* a Cube-inch of Water; and each square Foot half a Wine-pint; every Space of 4 Foot

Digitized by Google

ſquare, a Gallon; a Mile ſquare, 6914 Tons; a ſquare Degree ſuppoſe of 69 Engliſh Miles, will evaporate 33 Millions of Tons: And if the Mediterranean be eſtimated at forty degrees long and four broad, allowances being made for the Places where it is broader, by thoſe where it is narrower (and I am ſure I gueſs at the leaſt) there will be 160 Square degrees of Sea; and conſequently, the whole Mediterranean muſt loſe in Vapour, in a Summer's day, at leaſt 5280 Millions of Tons. And this Quantity of Vapour, tho' very great, is as little as can be concluded from the Experiment produced: And yet there remains another Cauſe, which cannot be reduced to Rule, I mean the Winds, whereby the Surface of the Water is licked up ſome times faſter than it exhales by the heat of the Sun; as is well known to thoſe that have conſidered thoſe drying Winds which blow ſometimes.

To eſtimate the Quantity of Water, the Mediterranean Sea receives from the Rivers that fall into it; is a very hard Task, unleſs one had the Opportunity to meaſure their Chanels and Velocity; and therefore we can only do it by allowing more than enough; that is, by aſſuming theſe Rivers greater than in all probability they be, and then comparing the Quantity of Water voided by the *Thames*, with that of thoſe Rivers whoſe Waters we deſire to compute.

The Mediterranean receives theſe conſiderable Rivers; the *Iberus*, the *Rhone*, the *Tiber*, the *Po*, the *Danube*, the *Neiſter*, the *Boryſtenes*, the *Tanais*, and the *Nile*; all the reſt being of no great Note, and their Quantity of Water inconſiderable: Theſe nine Rivers, we will ſuppoſe

ſuppoſe each of them to bring down ten times as much Water as the River *Thames*; not that any of them is ſo great in reality, but to comprehend with them all the ſmall Rivulets that fall into the Sea, which otherwiſe I know not how to allow for.

To calculate the Water of the *Thames*, I aſſume that at *Kingſton* Bridge where the Flood never reaches, and the Water always runs down, the breadth of the Chanel is 100 Yards, and its Depth 3, it being reduced to an Equality (in both which Suppoſitions I am ſure I take with the moſt) hence the Profil of the Water in this Place is 300 ſquare Yards: This multiplied by 48 Miles (which I allow the Water to run in 24 hours, at 2 Miles an hour) or 84480 Yards, gives 25344000 Cubick-yards of Water to be evacuated every day; that is, 20300000 Tons *per diem*; and I doubt not, but in the exceſs of my Meaſures of the Chanel of the River, I have made more than ſufficient allowance for the Waters of the *Brent*, the *Wandel*, the *Lea*, and *Darwent*, which are all worth notice, that fall into the *Thames* below *Kingſton*.

Now if each of the aforeſaid 9 Rivers yield 10 times as much Water as the *Thames* doth, 'twill follow that each of them yields but 203 Millions of Ton *per diem*, and the whole 9 but 1827 Million of Tons in a day; which is but little more than $\frac{1}{3}$ of what is proved to be raiſed in Vapour out of the Mediterranean in 12 hours time. Now what becomes of this Vapour when rais'd, and how it comes to paſs that the Current always ſets in at the Mouth of the Streights of *Gibralter*, ſhall immediately be ſhew'd: But firſt it is neceſſary to adver-

Digitized by Google

tiſe the Reader, that in making the Experiment herein mention'd, the Water uſed: had been ſalted to the ſame degree as is the common Sea-water, by the Solution of about a 40th part of Salt.

HAving thus ſhew'd by Experiment the Quantity of Water raiſed in Vapour from the Surface the Sea in a Days time, which was ſo far approved of by ſome Honourable Members of this Society, that I received their Commands to proſecute theſe Enquiries; and particularly, in relation to the Method uſed by Nature, to return the ſaid Vapours again into the Sea; which is ſo juſtly performed, that in many hundred of Years we are ſufficiently aſſured that the Sea has not ſenſibly decreaſed by the loſs in Vapour; nor yet abounded by the immenſe Quantity of freſh it receives continually from the Rivers. To demonſtrate this Equilibre of Receipt and Expence in the whole Sea is a Task too hard for me to undertake, yet in obedience to thoſe whom I have the Honour to ſerve, I ſhall here offer, what to me has hitherto ſeem'd the moſt ſatisfactory Account of this grand *Phænomenon*: I have in another place attempted to explain the manner of the riſing of Vapour by Warmth, by ſhewing, that if an Atom of Water were expanded into a Shell or Bubble, ſo as to be ten times as big in Diameter as when it was Water; ſuch an Atom would become ſpecifically lighter than Air, and riſe ſo long as that *Flatus* or warm Spirit that firſt ſeparated it from the Maſs of Water, ſhall continue to diſtend it to the ſame Degree; and that warmth declining, and the Air growing cooler and with alſo ſpecifically lighter, the Vapours conſe-

quently

Digitized by Google

quently ſhall ſtop at a certain Region of the Air, or elſe deſcend, which may happen upon ſeveral accounts, as I ſhall by and by endeavour to make out; yet I undertake not that this is the only principal of the riſe of Vapours, and that there may not be a certain ſort of Matter whoſe *Conatus* may be contrary to that of Gravity; as is evident in Vegitation, wherein the Tendency of the Sprouts is directly upwards, or againſt the Perpendicular. But whatever is the true Cauſe, it is in Fact certain, that warmth does ſeparate the Particles of Water, and emit them with a greater and greater Velocity, as the heat is more and more intenſe; as is evident in the Steam of a boiling Cauldron, wherein likewiſe the Velocity of the aſcent of the Vapours does viſibly decreaſe till they diſappear, being diſperſed into and aſſimulated with the Ambient Air. Vapours being thus raiſed by warmth, let us for a firſt Suppoſition put, that the whole Surface of the Globe were all Water very deep, or rather that the whole Body of the Earth were Water, and that the Sun had his diurnal courſe about it: I take it, that it would follow, that the Air of it ſelf would imbibe a certain Quantity of aqueous Vapors, and retain them like Salts diſſolved in Water; that the Sun warming the Air, and raiſing a more plentiful Vapour from the Water in the day-time, the Air would ſuſtain a greater proportion of Vapour, as warm Water will hold more diſſolved Salts, which upon the abſence of the Sun in the Nights would be all again diſcharg'd in Dews, analogous to the Precipitation of Salts on the cooling of the Liquors; nor is it to be believed that in ſuch Caſe there would be any diverſity of Weather, other than

Digitized by Google

periodically, every Year alike; the mixture of all terreſtrious, ſaline, heterogenious Vapours being taken away, which as they are variouſly compounded and brought by the Winds, ſeem to be the Cauſes of thoſe various Seaſons which we now find. In this caſe the Aiery Regions every where, at the ſame height, would be equally repleniſhed with the Proportion of Water it could contain, regard being only to be had to the different degree of warmth, from the nearneſs or diſtance of the Sun; and an eternal Eaſt-wind would blow all round the Globe, inclining only to the ſame ſide of the *Eaſt*, as the Latitude doth from the Equator; as is obſerved in the Ocean between the Tropicks.

Next let us ſuppoſe this Ocean interſperſed with wide and ſpacious Tracts of Land, with high Ridges of Mountains, ſuth as the *Pyrenean*, the *Alps*, the *Apenhine*, the *Carpathian* in *Europe*, *Taurus Caucaſus Imaus*, and ſeveral others in *Aſia*; *Atlas* and the *Montes Lunæ*, with other unknown Rridges in *Africa*, whence came the *Nile*, the *Nigre*, and the *Zaire*: And in *America*, the *Andes* and the *Apalatean* Mountains; each of which far ſurpaſs the uſual height to which the Aqueous Vapours of themſelves aſcend, and on the tops of which the Air is ſo cold and rarified, as to retain but a ſmall part of thoſe Vapours that ſhall be brought thither by Winds. Thoſe Vapours therefore that are raiſed copiouſly in the Sea, and by the Wind, are carried over the low Land to thoſe Ridges of Mountains, are there compelled by the Stream of the Air to mount up with it to the tops of the Mountains, where the Water preſently precipitates, gleeting down by the Crannies of the Stone; and part of the Vapour entering into the Ca-

verns

verns of the Hills, the Water thereof gathers as in an Alembick into the Baſons of Stone it finds; which being once fill'd, all the overplus of Water that comes thither runs over by the loweſt place, and breaking out by the ſides of the Hills, forms ſingle *Springs*. Many of theſe running down by the Valleys or Guts between the ridges of the Hills, and coming to unite form little Rivulets, or Brooks: many of theſe again, meeting in one common Valley and gaining the plain Ground, being grown leſs rapid become a River: and many of theſe being united in one common Channel, make ſuch Streams as the *Rhine*, the *Rhone*, the *Danube*, which latter, one would hardly think the Collection of Water condenſed out of Vapour, unleſs we conſider how vaſt a Tract of Ground that River drains, and that it is the Sum of all thoſe Springs which break out on the South ſide of the *Carpathian* Mountains, and on the North ſide of the immenſe Ridge of the *Alps*, which is one continued Chain of Mountains from *Switzerland*, to the *Black-Sea*. And it may almoſt paſs for a Rule, that the magnitude of a River, or the quantity of Water it evacuates, is proportionable to the length and height of the Ridges from whence its Fountains ariſe. Now this Theory of *Springs* is not a bare *Hypotheſis*, but founded ion Experience, which it was my luck to gain tn my abode at St. *Helena*, where in the Night ime, on the tops of the Hills, about 800 Yards above the Sea, there was ſo ſtrange a condenſation, or rather precipitation of the Vapours, that it was a great Impediment to my Cœleſtial Obſervations; for in the clear Sky, the Dew would fall ſo faſt, as to cover each half quarter of an Hour, my Glaſſes with little drops, ſo that

that if I was necessitated to wipe them so often, and my Paper on which I wrote my Observations would immediately be so wet with Dew, that it would not bear Ink: By which it may be suppos'd how fast the Water gathers in those mighty high Ridges I but now nam'd.

Thus is one part of the Vapours blown upon the Land return'd by the Rivers into the Sea, from whence they came; another part by the cool of the Night falls in Dews, or else in Rains, again into the Sea before it reaches the Land, which is by much the greatest part of the whole Vapours, because of the great extent of the Ocean, which the motion of the Winds does not traverse in a very long space of Time; and this is the Reason why the Rivers do not return so much into the *Mediterranean*, as is extracted into Vapour. A third part falls on the Low-Lands, and is the *Pabulum* of Plants, where yet it does not rest, but is again exhaled in Vapour by the action of the Sun, and is either carried by the Winds to the Sea to fall in Rain or Dew there, or else to the Mountains to be there turn'd into Springs; and tho' this does not immediately come to pass, yet after several Vicissitudes of rising in Vapour, and falling in Rain or Dews, each Particle of the Water is at length return'd to the Sea from whence it came. Add to this, that the Rain-waters after the Earth is fully sated with moisture, does, by the Vallies or lower parts of the Earth, find its way into the Rivers, and so is compendiously sent back to the Sea. After this manner is the Circulation perform'd, and I doubt not but this Hypothesis is more reasonable than that of those who derive all Springs from the Rain-waters, which yet are perpetual and without diminution, even

when

Digitized by Google

when no Rain falls for a long space of time; or that derive them from a Filtration or Percolation of the Sea-waters, tho' certain imaginary Tubes or Passages within the Earth wherein they lose their Saltness. This, besides many others, labouring under this principal Absurdity, that the greatest Rivers have their most copious Fountains farthest from the Sea, and whether so great quantities of fresh Water cannot reasonably be deriv'd any other way than in Vapour. This, if we may allow final Causes, seems to be the design of the Hills that their Ridges being plac'd thro' the midst of the Continents, might serve, as it were, for Alembicks to distil fresh Water for the use of Man and Beast, and their heights to give a descent to those Streams to run gently, like so many Veins of the *Macrocosm* to be the more benificial to the Creation. If the difference between Rain and Dew, and the cause why sometimes 'tis Cloudy, at other times Serene, be inquir'd, I can offer nothing like a proper Solution thereof, only with submission to propose Conjectures, which are the best I can find, *viz.* That the Air being heaped up by the meeting of two contrary Winds, when the *Mercury* is high, the Vapours are the better sustain'd and kept from Co-agulating or Condensing into Drops, whereby Clouds are not so easily generated; and in the Night the Vapours fall down single, as they arose in imperceptible Atoms of Water: Whereas, when the *Mercury* is low and the Air rarified by the Exhaustion thereof, by two contrary Winds blowing from the place; the Atoms of Air keep the Vapours not so well separated, and they Coalesce into visible Drops in the Clouds, and from thence are

Digitized by Google

are eaſily drawn into greater Drops of Rain; to which 'tis poſſible and not improbable, that ſome ſort of Saline or Angular Particles of Terreſtrial Vapour being immix'd with the Aqueous, which I take to be Bubbles, may cut or break their Skins or Coats, and ſo contribute to their more ſpeedy Condenſation into Rain.

The

Digitized by Google

The True Theory of the Tides, extracted from that admired Treatiſe of Mr. Iſaac Newton, *Intitituled*, Philoſophiæ Naturalis Principia Mathematica; *being a Diſcourſe preſented with that Book to the late King* James, *by Mr.* Edmund Halley.

IT may, perhaps, ſeem ſtrange, that this Paper, being no other than a partile Account of a Book long ſince publiſhed, ſhould now appear here; but the Deſire of ſeveral honourable Perſons, which could not be withſtood have obliged us to inſert it here, for the ſake of ſuch, who being leſs knowing in Mathematical Matters; and therefore not daring to adventure on the Author himſelf, are notwithſtanding, very curious to be informed of the Cauſes of Things; particularly of ſo general and extraordinary Phænomena, *as are thoſe of the Tides. Now this Paper having been drawn up for the late King* James's *Uſe, (in whoſe Reign the Book was publiſhed) and having given good Satisfaction to thoſe that got Copies of it; it is hoped the Savans of the higher Form will indulge us this Liberty we take to gratifie their Inferiours in point of Science; and not be offended, that we here inſiſt more largely upon Mr.* Newton's Theory of the Tides, *which, how plain and eaſie ſoever we find, is very little underſtood by the common Reader.*

THE

Digitized by Google

THE sole Principle upon which this Author proceeds to explain most of the great and surprizing Appearances of Nature, is no other then that of *Gravity*, whereby in the Earth all Bodies have a tendency towards its Centre; as is most evident: and from undoubted Arguments its proved, that there is such a Gravitation towards the Centre of the Sun, Moon, and all the Planets.

From this Principle, as a necessary Consequence, follows the Sphærical Figure of the Earth and Sea, and of all the other Cælestial Bodies: and tho' the tenacity and firmness of the Solid Parts, support the Inequalities of the Land above the Level; yet the Fluids, pressing equally and easily yielding to each other, soon restore the *Æquilibrium*, if disturbed, and maintain the exact Figure of the Globe.

Now this force of Descent of Bodies towards the Center, is not in all places alike, but is still less and less, as the distance from the Center encreases: and in this Book it is demonstrated, that this Force decreases as the Square of the distance increases; that is, the weight of Bodies and the force of their Fall is less, in parts more removed from the Center, in the proportion of the Squares of the Distance. So as for Example, a Ton weight on the Surface of the Earth, if it were raised to the height of 4000 Miles, which I suppose the Semidiameter of the Earth, would weigh but $\frac{1}{4}$ of a Ton, or 5 Hundred weight: If to 12000 Miles, or 3 Semidiameters from the Surface, that is 4 from the Center, it would weigh but $\frac{1}{16}$ part of the Weight on the Surface, or a Hundred and Quarter: So that it would be as easie for the

Strength

Digitized by Google

Strength of a Man at that height to carry a Ton weight, as here on the Surface a $100\frac{1}{4}$. And in the same Proportion does the Velocities of the fall of Bodies decrease; For whereas on the Surface of the Earth all things fall 16 Foot in a second, at one Semidiameter above, this fall is but four Foot; and at three Semidiameters, or four from the Centre, it is but $\frac{1}{16}$ of the Fall at the Surface, or but one Foot in a second: And at greater Distances both Weight and Fall become very small, but yet at all given Distances is still some thing, tho' the Effect become insensible. At the distance of the Moon (which I will suppose 60 Semidiameters of the the Earth) 3600 Pounds weigh but one Pound, and the fall of Bodies is but $\frac{1}{3600}$ of a Foot in a second, or 16 Foot in a Minute; that is, a Body so far off descends in a Minute no more than the same at the Surface of the Earth would do in a Second of Time.

As was said before, the same force decreasing after the same manner is evidently found in the Sun, Moon, and all the Planets; but more especially in the Sun, whose Force is prodigious; becoming sensible even in the immense distance of *Saturn*: This gives room to suspect, that the force of Gravity is in the Cœlestial Globes proportional to the quantity of Matter in each of them: And the Sun being at least ten Thousand times as big as the Earth, its Gravitation or attracting Force, is found to be at least ten Thousand times as much as that of the Earth, acting on Bodies at the same distance.

This Law of the decrease of Gravity being demonstratively proved, and put past contradiction; the Author with great Sagacity, inquires into the necessary Consequences of this,

Sup-

Digitized by Google

Supposition; whereby he finds the genuine Cause of the several Appearances in the Theory of the Moon and Planets, and discovers the hitherto unknown Laws of the Motion of Comets, and of the Ebbing and flowing of the Sea. Each of which are Subjects that have hitherto taken up much larger Volumes; but Truth being uniform, and always the same, it is admirable to observe how easily we are enabled to make out very abstruse *and difficult Matters*, when once true and genuine Principles are obtained: And on the other hand it may be wondred, that, notwithstanding the great facility of truth, and the perplexity and nonconsequences that always attend erroneous Suppositions, these great Discoveries should have escaped the acute Disquisitions of the best Philosophical Heads of all past Ages, and be reserv'd to these our Times. But that wonder will soon cease, if it be consider'd how great improvements Geometry has receiv'd in our Memory, and particularly from the profound Discoveries of our incomparable Author.

The Theory of the Motion of the primary *Planets* is here shewn to be nothing else, but the contemplation of the Curve Lines which Bodies cast with a given Velocity, in a given Direction and at the same time drawn towards the Sun by its gravitating Power, would describe. Or, which is all one, that the Orbs of the Planets are such Curve Lines as a Shot from a Gun describes in the Air, being cast according to the direction of the Piece, but bent in a crooked Line by the supervening Tendency towards the Earths Centre: And the Planets being supposed to be projected with a given Force, and attracted towards the Sun, after the aforesaid man-

Digitized by Google

manner, are here proved to describe such Figures, as answer punctually to all that the Industry of this and the last Age has observ'd in the Planetary Motions. So that it appears, that there is no need of solid Orbs and Intelligences, as the Antients imagin'd, nor yet of *Vortices* or Whirlpools of the Celestial Matter, as *Des Cartes* supposes; but the whole Affair is simply and mechanically performed, upon the sole Supposition of a Gravitation towards the Sun; which cannot be denied.

The Motion of *Comets* is here shewn to be compounded of the same Elements, and not to differ from Planets, but in their greater swiftness, whereby overpowering the Gravity that should hold them to the Sun, as it doth the Planets, they flie off again, and distance themselves from the Sun and Earth, so that they soon are out of our sight. And the imperfect Accounts and Observations Antiquity has left us, are not sufficient to determine whether the same Comet ever return again. But this Author has shewn how Geometrically to determine the Orb of a Comet from Observations, and to find his distance from the Earth and Sun, which was never before done.

The third thing here done is the Theory of the Moon, all the Inequalities of whose Motion are proved to arise from the same Principles, only here the effect of two Centers operating on, or attracting a projected Body comes to be considered; for the Moon, tho principally attracted by the Earth, and moving round it, does together with the Earth, move round the Sun once a Year, and is according as she is, nearer or farther from the Sun, drawn by him more or less than the Center of the Earth, about

Digitized by Google

which ſhe moves; whence ariſe ſeveral Irregularities in her Motion, of all which, the Author in this Book, with no leſs Subtility than Induſtry, has given a full account. And tho' by reaſon of the great Complication of the Problem, he has not yet been able to make it purely Geometrical, 'tis to be hoped, that in ſome farther Eſſay he may ſurmount the difficulty: And having perfected the Theory of the Moon, the long deſir'd diſcovery of the Longitude (which at Sea is only practicable this way) may at length be brought to light, to the great Honour of your Majeſty and Advantage of your Subjects.

All the ſurprizing Phænomena of the Flux and Reflux of the Sea, are in like manner ſhewn to proceed from the ſame Principle; which I deſign more largely to inſiſt on, ſince the matter of Fact is in this caſe much better known to your Majeſty than in the foregoing.

If the Earth were alone, that is to ſay, not affected by the Actions of the Sun and Moon, it is not to be doubted, but the Ocean, being equally preſs'd by the force of Gravity towards the Center, would continue in a perfect ſtagnation, always at the ſame height, without either Ebbing or Flowing; but it being here demonſtrated, that the Sun and Moon have a like Principle of Gravitation towards their Centers, and that the Earth is within the Activity of their Attractions, it will plainly follow, that the Equality of the preſſure of Gravity towards the Center will thereby be diſturb'd; and tho' the ſmallneſs of theſe Forces, in reſpect of the Gravitation towards the Earths Center, renders them altogether imperceptible

Digitized by Google

perceptible by any Experiments we can deviſe, yet the Ocean being fluid and yeilding to the leaſt force, by its riſing ſhews where it is leſs preſt, and where it is more preſt by its ſinking.

Now if we ſuppoſe the force of the Moons Attraction to decreaſe as the Square of the Diſtance from its Center increaſes (as in the Earth and other Celeſtial Bodies) we ſhall find, that where the Moon is perpendicularly either above or below the Horizon, either in Zenith or Nadir, there the force of Gravity is moſt of all diminiſhed, and conſequently that there the Ocean muſt neceſſarily ſwell by the coming in of the Water from thoſe parts where the Preſſure is greateſt, *viz.* in thoſe places where the Moon is near the Horizon: But that this may be the better underſtood, I thought it needful to add the following Figure, (*Vide Fig.* 1. *Plate* 1.) where *M* is the Moon, *E* the Earth, *C* its Center, and *Z* the place where the Moon is in the Zenith, *N* where in the Nadir.

Now by the Hypotheſis it is evident, that the Water in *Z*, being nearer, is more drawn by the Moon, than the Center of the Earth *C*, and that again more than the Water in *N*, wherefore the Water in *Z* hath a tendency towards the Moon, contrary to that of Gravity, being equal to the exceſs of the Gravitation in *Z*, above that in *C*: And in the other caſe, the Water in *N*, tending leſs towards the Moon than the Center *C*, will be leſs preſſed, by as much as is the difference of the Gravitations towards the Moon in *C* and *N*. This rightly underſtood, it follows plainly, that the Sea, which otherwiſe would be Spherical, upon the Preſſure of the Moon, muſt form it

Digitized by Google

ſelf into a Spheroidal or Oval Figure, whoſe longeſt Diameter is where the Moon is vertical, and ſhorteſt where ſhe is in the Horizon; and that the Moon ſhifting her Poſition as ſhe turns round the Earth once a Day, this Oval of Water ſhifts with her, occaſioning thereby the two Floods and Ebbs obſervable in each 25 Hours.

And this may ſuffice as to the general Cauſe of the Tides; it remains now to ſhew how naturally this motion accounts for all the Particulars that have been obſerv'd about them; ſo that there can be no room left to doubt, but that this is the true cauſe thereof.

The Spring Tides upon the New and Full Moons, and Neap Tides on the Quarters, are occaſion'd by the attractive Force of the Sun in the New and Full, conſpiring with the Attraction of the Moon, and producing a Tide by their united Forces: Whereas in the Quarters, the Sun raiſes the Water where the Moon depreſſes it, and the contrary; ſo as the Tides are made only by the difference of their Attractions. That the force of the Sun is no greater in this caſe, proceeds from the very ſmall Proportion the Semidiameter of the Earth bears to the vaſt diſtance of the Sun.

It it alſo obſerv'd, that *cæteris paribus*, the Æquinoctial Spring Tides in *March* and *September*, or near them, are the Higheſt, and the Neap Tides the loweſt; which proceeds from the greater Agitations of the Waters, when the fluid *Spheroid* revolves about a great Circle of the Earth, than when it turns about in a leſſer Circle; it being plain, that if the Moon were conſtituted in the Pole and there ſtood, that the *Spheroid* would have a fixt Poſition

Digitized by Google

ſition, and that it would be always high Water under the Poles, and low Water every where under the Æquinoctial: And therefore the nearer the Moon approaches the Poles, the leſs is the agitation of the Ocean, which is of all the greateſt, when the Moon is in the Æquinoctial, or fartheſt diſtant from the Poles. Whence the Sun and Moon, being either conjoined or oppoſite in the Æquinoctial, produce the greateſt Spring Tides; and the ſubſequent Neap Tides, being produc'd by the Tropical *Moon in the* Quarters, are always the leaſt Tides; whereas in *June* and *December*, the Spring Tides are made by the Tropical Sun and Moon, and therefore leſs vigorous; and the Neap Tides by the Æquinoctial Moon, which therefore are the ſtronger: Hence it happens, that the difference between the Spring and Neap Tides in theſe Months, is much leſs conſiderable than in *March* and *September*. And the reaſon why the very higheſt Spring Tides are found to be rather before the Vernal and after the Autumnal Equinox, *viz.* in *February* and *October*, than preciſely upon them, is, becauſe the Sun is nearer the Earth in the Winter Months, and ſo comes to have a greater effect in producing the Tides.

Hitherto we have conſider'd ſuch Affections of the Tides as are Univerſal, without relation to particular Caſes; what follows from the differing Latitudes of places, will be eaſily underſtood by the following Fig. (*Vide Fig.* 2. *Plate* 1.)

Let *A p E P* be the Earth cover'd over with very deep Waters, *C* its Center, *P*, *p*, its Poles, *A E* the Æquinoctial, *F f* the parallel of Latitude of a Place, *D d* another Parallel at equal diſtance on the other ſide of the Æqui-

Digitized by Google

noctial, *H h* the two Points where the Moon is vertical, and let *K k* be the great Circle, wherein the Moon appears Horizontal. It is evident, that a Spheriod describ'd upon *H h*, and and *K k* shall nearly represent the Figure of the Sea, and *Cf*, *CD*, *CF*, *Cd* shall be the hights of the Sea in the places *f*, *D*, *F*, *d*, in all which it is High-water: And seeing that in twelve Hours time, by the diurnal Rotation of the Earth, the Point *F* is transferr'd to *f*, and *d* to *D*: The hight of the Sea *CF* will be that of the High-water when the Moon is present, and *Cf* that of the other High-water, when the Moon is under the Earth: Which in the case of this Figure is less than the former *CF*. And in the opposite Parallel *D d* the contrary happens. The Rising of the Water being always alternately greater and less in each place, when it is produc'd by the Moon declining sensibly from the Æquinoctial; that being the greatest of the two High-waters in each diurnal Revolution of the Moon, wherein she approaches nearest either to the Zenith or Nadir of the place: Whence it is that the Moon in the Northern Signs, in this part of the World, makes the greatest Tides when above the Earth, and in Southern Signs, when under the Earth; the Effect being always the greatest where the Moon is farthest from the Horizon, either above or below it. And this alternate increase and decrease of the Tides has been observ'd to hold true on the Coast of *England*, at *Bristol* by Capt. *Sturmy*, and at *Plymouth* by Mr. *Colepresse*.

But the motions hitherto mention'd are somewhat alter'd by the Libration of the Water, whereby, tho' the Action of the *Luminaries*

Digitized by Google

ries ſhould ceaſe, the Flux and Reflux of the Sea would for ſome time continue: This Conſervation of the impreſs'd Motion diminiſhes the differences that otherwiſe would be between two conſequent Tides, and is the reaſon why the higheſt Spring-Tides are not preciſely on the New and Full Moons, nor the Neaps on the Quarters; but generally they are the third Tides after them, and ſometimes later.

All theſe things would regularly come to paſs, if the whole Earth were cover'd with Sea very deep; but by reaſon of the ſhoalneſs of ſome places, and the narrowneſs of the Streights, by which the Tides are in many caſes propagated, there ariſes a great diverſity in the Effect, and not to be accounted for, without an exact Knowledge of all the Circumſtances of the Places, as of the Poſition of the Land, and the Breadth and Depth of the Channels by which the Tide flows; for a very ſlow and imperceptible motion of the whole Body of the Water, where it is (for example) 2 Miles deep, will ſuffice to raiſe its Surface 10 or 12 Feet in a Tides time; whereas, if the ſame quantity of Water were to be convey'd upon a Channel of 40 Fathoms deep, it would require a very great Stream to effect it, in ſo large Inlets as are the Channel of *England* and the *German* Ocean; whence the Tide is found to ſet ſtrongeſt in thoſe places where the Sea grows narroweſt; the ſame quantity of Water being to paſs through a ſmaller Paſſage: This is moſt evident in the *Streights*, between *Portland* and *Cape de Hague* in *Normandy*, where the Tide runs like a Sluce; and would be yet more between *Dover* and *Calis*, if the Tide coming a-

Digitized by Google

bout the Iſland from the North did not check it. And this force being once impreſs'd upon the Water, continues to carry it above the level of the ordinary height in the Ocean, particularly where the Water meets a direct Obſtacle, as it is at St. *Malo*'s; and where it enters into a long Channel, which running far into the Land, grows very ſtreight at its Extremity; as it is in the *Severn-Sea* at *Chepſtow* and *Briſtol*.

This ſhoalneſs of the Sea and the intercurrent Continents are the reaſon, that in the open Ocean the time of High-water is not at the Moons appulſe to the Meridian, but always ſome Hours after it; as it is obſerv'd upon all the Weſt-Coaſt of *Europe* and *Africa*, from *Ireland* to the *Cape of Good-Hope*: In all which a S. W. Moon makes High-water, and the ſame is reported to be on the Weſt ſide of *America*. But it would be endleſs to account all the particular Solutions, which are eaſie Corollaries of this *Hypotheſis*; as why the *Lakes*, ſuch as the *Caſpian Sea*, and *Mediterranian Seas*, ſuch as the *Black Sea*, the *Streights* and *Baltick*, have no ſenſible Tides: For *Lakes* having no Communication with the Ocean, can neither increaſe nor diminiſh their Water, whereby to riſe and fall; and Seas that communicate by ſuch narrow Inlets, and are of ſo immenſe an Extent, cannot in a few Hours time receive or empty Water enough to raiſe or ſink their Surface any thing ſenſibly.

Laſtly, to demonſtrate the excellency of this Doctrine, the Example of the Tides in the Port of *Tunking* in *China*, which are ſo extraordinary, and differing from all others we have yet heard of, may ſuffice. In this Port there is

but

but one Flood and Ebb in 24 Hours; and twice in each Month, *viz.* when the Moon is near the Æquinoctial there is no Tide at all, but the Water is stagnant; but with the Moons declination there begins a Tide, which is greatest when she is in the Tropical Signs: Only with this difference, that when the Moon is to the Northward of the Æquinoctial, it Flows when she is above the Earth, and Ebbs when she is under, so as to make High-water at Moons-setting, and Low-water at Moons-rising; But on the contrary, the Moon being to the Southward, makes High-water at rising and Low-water at setting; it Ebbing all the time she is above the Horizon. As may be seen more at large in the *Philosophical Transaction*, Numb. 162.

The Cause of this odd Appearance is propos'd by Mr. *Newton*, to be from the concurence of two Tides; the one propagated in six Hours out of the great *South-Sea* along the Coast of *China*; the other out of the *Indian-Sea*, from between the Islands in twelve Hours, along the Coast of *Malacca* and *Cambodia*. The one of these Tides, being produc'd in North-Latitude, is, as has been said, greater, when the Moon being to the North of the Equator is above the Earth, and less when she is under the Earth. The other of them, which is propagated from the *Indian-Sea*, being raised in South-Latitude, is greater when the Moon declining to the South, is above the Earth, and less when she is under the Earth: So that of these Tides alternately greater and lesser, there comes always successively two of the greater and two of the lesser together every day; and the High-water falls always between the times of the

Digitized by Google

the arrival of the two greater Floods; and the Low-water between the arrival of the two lesser Floods. And the Moon coming to the Æquinoctial, and the alternate Floods becoming equal, the Tide ceases and the Water stagnates: But when she has pass'd to the other side of the Equator, those Floods which in the former Order were the least, now becoming the greatest, that That before was the time of High-water now becomes the Low-water, and the Converse. So that the whole appearance of these strange Tides, is without any forcing naturally deduc'd from these Principles, and is a great Argument of the certainty of the whole *Theory*.

Digitized by Google

A Theory of the Variation *of the* Magnetical Compaſs, *by Mr.* Ed. Halley *Fellow of the R. S.*

THE variation of the Compaſs (by which I mean the deflection of the Magnetical Needle from the true Meridian) is of that great concernment in the Art of Navigation, that the neglect thereof, does little leſs than render uſeleſs one of the nobleſt Inventions Mankind ever yet attained to. And for this cauſe all Ships of Conſequence (eſpecially thoſe bound beyond the Equator) carry with them Inſtruments on purpoſe to obſerve this variation: That ſo the Courſe ſteer'd by the Compaſs, may be reduc'd to the true Courſe in reſpect of the Meridian.

Now altho' the great utility that a perfect knowledge of the Theory of the Magnetical Direction would afford to Mankind in general, and eſpecially to thoſe concern'd in Sea Affairs, ſeems as ſufficient incitement to all Philoſophical and Mathematical Heads, to take under ſerious Conſideration the ſeveral *Phænomena*, and to endeavour to reconcile them by ſome general Rule: Yet ſo it is; that almoſt all the Authors, from whom a Diſcourſe of this kind ought to have been expected, paſs by in ſilence the difficulties they here encounter. And thoſe that mention this variation: By affirming it to proceed from Cauſes altogether uncertain (as are the caſual lying of Iron Mines and Loadſtones in the Earth) put a ſtop to all further Contemplation

Digitized by Google

plation; and give discouragement to those that would otherwise undertake this Enquiry. 'Tis true, that not long since one Mr. *Bond*, an old Teacher of Navigation, put forth a small Treatise wherein he pretends to calculate the variation: But he limits his Hypothesis to the City of *London*, affirming himself (as he had a great deal of reason) that the same *Calculus* is not sufficient for other places; whereby it appears that this Rule is far short of the so much desir'd general one.

Now although (through want of sufficient Observations and some other difficulties which I shall anon shew) I cannot pretend perfectly to establish the Numbers and Rules of a *Calculus* which shall precisely answer to the variations of all parts of the World: Yet I suppose it will not be unacceptable to the curious to propose something of a light into this abstruse Mystery; which, if no other, may have this good effect, to stir up the Philosophical *Genii* of the Age to apply themselves more attentively to this useful speculation. But before I proceed, 'twill be necessary to lay down the Grounds upon which I raise my Conclusions; and at once to give a Synopsis of those variations which I have reason to look upon as sure, being mostly the Observations of Persons of good Skill and Integrity.

A

Digitized by Google

A

TABLE OF VARIATIONS.

Names of Places.	*Longitude from Lon.*	*Latitude.*	*Anno Dom.*	*Variation Observ'd.*
	d m	*d m*		*d m*
London	0 0	51 32 N	1580	11 15 E
			1622	6 0 E
			1634	4 5 E
			1672	2 30W
Paris	2. 25 E	48. 51 N	1683	4 30W
			1640	3 00 E
			1666	0 0
			1681	2 30W
Uraniburg	13. 0 E	55.54 N	1672	2 35W
Copenhagen	12. 53 E	55. 41 N	1649	1 30 E
			1672	3 35W
Dantzick	19. 0 E	54.23 N	1679	7 00W
Mompelier	4. 0 E	43.37 N	1674	1 10W
Brest	4. 25 W	48. 23 N	1680	1 45W
Rome	13. 0 E	41. 50 N	1681	5 0 W
Bayonne	1. 20 W	43. 30 N	1680	1 20W
Hudson's Bay	79. 40 W	51 00 N	1668	19 15W
In *Hud.* Straights	57. 00 W	61 00 N	1668	29 30W
In *Baffius* Bay at Sir *Thomas Smiths* Sound	80. 00 W	78 00 N	1616	57 00W

Names

Digitized by Google

Names of Places.	*Longitude.*			*Latitude.*			*Anno Dom.*	*Variation*		
	d	*m*		*d*	*m*			*d*	*m*	
At Sea	50	0	W	38	40	N	1682	7	30	W
At Sea	31	30	W	43	50	N	1682	5	30	W
At Sea	42	0	W	21	0	N	1678	0	40	E
Cape St. *Aug.* of *Brazile*	35	30	W	8	0	S	1670	5	30	E
Cape Frio	41	10	W	22	40	S	1670	12	10	E
At Sea off of the Mou. of the River of *Plate*	53	00	W	39	30	S	1670	20	30	E
At the East Entrance of *Magellan* Straits	68	00	W	52	30	S	1670	17	00	E
At the W. Entrance of the *Magellan* Straits	75	00	W	53	00	S	1670	14	10	E
Baldivia	73	00	W	40	00	S	1670	8	10	E
At Cape d' *Agulhas*	16	30	E	34	50	S	1622	2	00	W
							1675	8	00	W
At Sea	1	0	E	34	30	S	1675	0	0	
At Sea	20	0	W	34	0	S	1675	10	30	E
At Sea	32	0	W	24	0	S	1675	10	30	E
At St. *Helens*	6	30	W	16	0	S	1677	0	40	E
At *Ascension*	14	30	W	7	50	S	1678	1	00	E
At *Johanna*	44	00	E	12	15	S	1675	19	30	W
At *Monbasa*	40	00	E	4	00	S	1675	16	00	W
At *Zocatra*	56	00	E	12	30	N	1674	17	00	W
At *Aden*, at the M. of the *Red Sea*	47	30	E	13	00	N	1674	15	00	W
At *Diego Rois*	61	0	E	20	0	S	1676	20	30	W
At Sea	64	30	E	0	0		1676	15	30	W
At Sea	55	0	E	27	0	S	1676	24	00	W
At *Bombay*	72	30	E	19	0	N	1676	12	00	W
At Cape *Comorin*	76	00	E	8	15	N	1680	8	48	W
At *Ballasore*	87	00	E	21	30	N	1680	8	20	W
At Fort St. *George*	80	00	E	13	15	N	1680	8	10	W
At the W. point of *Java*	104	0	E	6	40	S	1676	3	10	W

Digitized by Google

At Sea	58	00	E	39	0	S	1677	27	30 W
At the Isle of St. *Paul*	72	0	E	38	0	S	1677	23	30 W
At *Van Diemens* Land	142	0	E	42	25	S	1642	0	0
At new *Zealand*	170	0	E	40	50	S	1642	9	0 E
At Three Kings Isle in New *Zeland*	169	30	E	34	35	S	1642	8	40 E
At the Isle *Rotterdam* in the South Sea	184	00	E	20	15	S	1642	6	20 E
on the Coast of *N. Guniea*	149	00	E	4	30	S	1643	8	45 E
at the W. p. of *N. Guniea*	126	00	E	0	26	S	1643	5	30 E

Tho' I could wish we could obtain from the *Spaniards* what Variations they find in their Voyages from the *Manilhas* towards *Acapulco*, thorough the North part of the South Sea; as likewise what it is at *Japan*, from the *Dutch*: Yet (considering the number of these Observations I have collected, and that they are made in parts of the World so remote from *Europe*, and from one another) I suppose that the Theory that answers these will scarce fail in those Regions from whence we have as yet no account. But first we must make some remarkes upon the foregoing Table: And, First,

That in all *Europe* the variation at this time is *West*, and more in the Eastern Parts thereof than the Western: As likewise that it seems throughout to be upon the increase that way.

Secondly, That on the Coast of *America*, about *Virginia*, *New-England* and *New-Found-Land*, the variation is likewise Westerly; and that it increases all the way as you go Northerly along the Coast so as to be above 20 Degrees at *New-found-Land*, nearly 30 gr. in *Hudsons Straits*, and not less than 57 Degrees in *Baffins*

Digitized by Google

Baffins Bay; also, that as you Sail Eastward from this Coast the variation diminishes. From these two it is a Legitimate Corallary: That *Somewhere between* Europe, *and the North part of* America, *there ought to be an Easterly Variation, or at least no Westerly.* And so I conjecture it is about the Eastermost of the *Tercera Islands*.

Thirdly, That on the Coast of *Brasile* there is East variation, which increases very notably as you go to the Southward so as to be 12 Degrees at *Cape Frio*, and over against the River of *Plate* 20 ½ Degrees: And from thence Sailing Southwesterly to the Straits of *Magellan* it decreases 17 Degrees, and at the West Entrance but 14 Degrees.

Fourthly, That at the Eastward of *Brasile* properly so called, this Easterly variation decreases, so as to be very little at St. *Helena* and *Ascension*, and to be quite gone and the Compass Point true about 18 Degrees of Longitude West from the Cape of *Good-hope*.

Fifthly, That to the Eastward of the aforesaid Places a Westward variation begins, which Reigns in the whole *Indian* Sea, and arises to no less than Eighteen Degrees under the Equator itself, about the Meridian of the Northern part of *Madagascar*; and near the same Meridian but in 39. Degrees South Latitude it is found full 27 ½ Degrees: From thence Easterly the West variation decreases, so as to be little more than eight Degrees at *Cape Comorin*, and than three Degrees upon the Coast of *Java*; and to be quite extinct about the *Molucca Islands*, as also a little to the Westwards of *Van Diemen*

Digitized by Google

Diemens Land found out by the *Dutch* in 1642.

Sixthly, That to the Eastward of the *Moluccas* and *Van Diemens* Land in South Latitude there arises another Easterly Variation, which seems not so great as the former, nor of so large extent; for that at the Island *Rotterdam* it is sensibly less than upon the East Coast of *New Guinea*, and, at the rate it decreases, it may well be suppos'd, that about 20 Degrees farther East or 225 Degrees East Longitude from *London*, in the Latitude of 20 Degrees South, a Westerly Variation begins.

Seventhly, That the variations observ'd by the Honourable Sir *John Norborough* at *Baldivia* and at the West Entrance of the *Straights* of *Magellan* do plainly shew, that That East variation, noted in our third Remark, is decreasing apace; and that it cannot reasonably extend many Degrees into the South Sea from the Coast of *Peru* and *Chili*, leaving room for a small Westerly variation, in that Tract of the unknown World that lies in the mid-Way between *Chili* and *New-Zealand*, and between *Hounds-Island* and *Peru*.

Eightfily, That in Sailing North-West from St. *Helena* by *Ascension* as far as the Equator the variation continues very small East, and as it were constantly the same: So that in this part of the World the Course, wherein there is no variation, is evidently no Meridian, but rather North-West.

Ninthly, That the Entrance of *Hudson's Straights* and the Mouth of the River of *Plate* being nearly under the same Meridian, at the

Digitized by Google

one place the Needle varies 29½ Degrees to the *West*; at the other 20½ Degrees to the *East*. This plainly demonstrates the impossibility of reconciling these variations by the Theory of *Bond*; *which is by two Magnetical Poles and an Axis, inclined to the Axis of the Earth*; from whence it would follow, That *under the same Meridian the Variation should be in all places the same way.*

These things being premised may serve as a sure Foundation to raise the superstructure of a Theory upon. But first it would not be amiss to shew hereby the mistake of *Gilbert* and *Des Cartes*: The first whereof supposes; that *the Earth itself being in all its parts Magnetical, and the Water not; wheresoever the Land is, thither also should the Needle turn, as to the greater quantity of Magnetical Matter.* But this in many instances is not true; but most remarkably upon the Coast of *Brasile*, where the Needle is so far from being attracted by the Land, that it turns the quite contrary way, leaving the Meridian to lye N B E, which is just along the Coast. As to the Position of *Des Cartes*, *that the Iron and Loadstones hid in the Bowels of the Earth and the Bottom of the Sea may be the Causes that the Needle varies*; if we consider for how great a part of the Earths Surface, *ex gr.* in the whole *Indian* Sea, the Needle declines the same way, and that regularly, 'Twill follow that the attracting Substance that occasions it, must be very far distant. Now by Experience we find the little force that Iron Guns have upon the Compass in Ships (their Vertue, tho' they be demiculverins, or greater Cannon, being not perceptible at four or five Yards distance) and the

the Experiments now before the *Royal Society* do plainly ſhew, how little a Magnetiſm there is in moſt crude Iron Ores: What quantity thereof muſt be then ſuppos'd to make ſo powerful a Diverſion at two or three Thouſand Miles diſtance? Yet I cannot deny that in ſome places near the Shoar, or in Shoal-Water, the Needle may be irregularly directed from the aforeſaid Cauſes, and that not a little, as *Gaſſendus* gives a notable inſtance of the Iſland *Elba* in the Mediterranean Sea: But theſe differences from the general Direction are always ſigns of the nearneſs of thoſe Magnetical Subſtances, for the Production whereof that Iſland *Elba* has been famous from all Antiquity. Beſides, againſt both *Des Cartes* and *Gilbert*, the change of the variation, which has been within theſe Hundred Years laſt paſt more than 15 gr. at *London*, is an entire Demonſtration; tho' *Des Cartes* does not ſtick to ſay, that the tranſportation of Iron from place to place, and the growth of new Iron within the Earth, where there was none before, may be the cauſe thereof. The ſame holds likewiſe againſt the *Hypotheſis* of *Magnetical Fibres*, which *Kircher* maintains.

Now to propoſe ſomething that may anſwer the ſeveral appearances, and introduce nothing ſtrange in Philoſophy, after a great many cloſe Thoughts, I can come to no other Concluſion than that, *The whole Globe of the Earth is one great Magnet, having four Magnetical Poles, or Points of Attraction, near each Pole of the Equator Two; and that, in thoſe parts of the World which lye near adjacent to any one of thoſe Magnetical Poles, the Needle is governed thereby, the neareſt Pole being always predominant over the more remote.* The parts of the Earth wherein theſe

Digitized by Google

Magnetical *Poles* lie, cannot as yet be exactly determin'd for want of ſufficient *Data* to proceed Geometrically; but, as near as Conjecture can reach, I reckon that the *Pole*, which is at preſent neareſt to us, lies in or near the Meridian of the Lands end of *England*, and not above ſeven Degrees from the Pole Arctick, by this *Pole* the variations in all *Europe* and *Tartary*, and the *North Sea* are principally govern'd, tho' with regard to the other Northern Pole, whoſe ſituation is in a *Meridian* paſſing about the middle of *California*, and about 15 gr. from the North Pole of the World; to this the Needle has chiefly reſpect in all the North *America*, and in the two Oceans on either ſide thereof, from the *Azores* Weſtward to *Japan*, and farther. The two Southern Poles are rather farther diſtant from the South Pole of the World: The one about ſixteen Degrees therefrom, is in a Meridian, ſome twenty Degrees to the Weſtward of *Magellan Straights*, or ninty five Degrees Weſt from *London:* This commands the Needle in all the *South-America*, in the *Pacifick Sea*, and the greateſt part of the *Ethiopick* Ocean. The Fourth and laſt *Pole* ſeems to have the greateſt Power and largeſt Dominions of all, as it is the moſt remote from the Pole of the World, being little leſs than 20 Degrees diſtant there-from in the Meridian, which paſſes through *Hollandia Nova* and the Iſland *Celebes* about one hundred and twenty Degrees Eaſt from *London*; this Pole is predominant in the South part of *Africa*, in *Arabia* and the *Red Sea*, in *Perſia*, *India*, and its Iſlands, and all over the *Indian Sea*, from the Cape of *Good-Hope* Eaſtwards to the middle of the great South Sea that divides *Aſia* from *America*. This

ſeems

Digitized by Google

ſeems to be the preſent Diſpoſition of the Magnetical Vertue throughout the whole Globe of the Earth; it remains to ſhew how this Hypotheſis makes out all the variations that have been obſerv'd of late; and how it anſwers to our ſeveral Remarks drawn from the Table. And firſt it is plain, that (our *European* North *Pole* being in the Meridian of the Lands end of *England*) all places more Eaſterly than that will have it on the Weſt ſide of their Meridian, and conſequently the Needle, reſpecting it with its Northern Point, will have a Weſterly variation, which will ſtill be greater as you go to the Eaſtwards, till you come to ſome Meridian of *Ruſſia* where 'twill be greateſt, and from thence decreaſe again. Thus at *Breſt* the variation is but $1\frac{3}{4}$ Degrees, at *London* $4\frac{1}{2}$ Degrees; but at *Dantzick* ſeven Degrees Weſt. To the Weſtward of the Meridian of the Lands end, the Needle ought to have an Eaſterly variation; were it not that (by approaching the *American* Northern Pole, which lies on the Weſt ſide of the Meridian, and ſeems to be of greater force than this other) the Needle is drawn thereby Weſtwards, ſo as to counterballance the direction given by the *European Pole*, and to make a ſmall Weſt variation in the Meridian of the Lands end itſelf. Yet I ſuppoſe that about the Meridian of the Iſle *Tercera*, our neareſt Pole may ſo far prevail as to give the Needle a little turn to the Eaſt, tho' but for a very ſmall ſpace: The Counterballance of thoſe two Poles permitting no conſiderable variation in all the Eaſtern Parts of the *Atlantick* Ocean; nor upon the Weſt Coaſts of *England* and *Ireland*, *France*, *Spain* and *Barbary*. But to the Weſtwards of the *Azores* the Power of the *American*

Digitized by Google

Pole overcoming that of the *European* the Needle has chiefly reſpect thereto, and turns ſtill more and more towards it as you approach it. Whence it comes to paſs, that on the Coaſt of *Virginia*, *New-England*, *New-found-Land*, and in *Hudſon*'s-*Straights* the variation is Weſtward; that it decreaſes as you go from thence towards *Europe*, and that it is leſs in *Virginia* and *New-England*, than in *New-found-Land*, and *Hudſon*'s-*Straights*. This Weſterly variation again decreaſes, as you paſs over the *North America*; and about the Meridian of the middle of *California* the Needle again points due North; and from thence Weſtward to *Tedzo* and *Japan*, I make no doubt but the variation is Eaſterly, and half the Sea over no leſs than fifteen Degrees, if there be any truth in this Hypotheſis of mine. Therefore I propoſe this as a trial, that the whole may be ſcann'd thereby; and I conceive it will not be hard to know of the *Spaniards* how it is, who ſo frequently ſail through that Ocean, in their return from the *Manilha* Iſles. This Eaſt variation extends over *Japan*, *Tedzo*, *Eaſt-Tartary*, and part of *China*, till it meet with the Weſterly, which is govern'd by the *European* North Pole, and which I ſaid was greateſt ſomewherein *Ruſſia*.

Towards the Southern Pole the effect is much the ſame, only that here the South Point of the Needle is attracted. Hence it will follow, that the variation on the Coaſt of *Brazile*, at the River of *Plate*, and ſo on to the Straits of *Magellan* ſhould be Eaſterly (as in our third Remark); if we ſuppoſe a Magnetical Pole ſituate about twenty Degrees more Weſterly than the Straights of *Magellan*. And this Eaſterly variation doth extend Eaſtward over the greateſt part

Digitized by Google

part of the *Ethiopick* Sea, till it be counterpoised by the Vertue of the other Southern *Pole*; as it is about mid-way between the Cape of *Good-Hope*, and the Isles of *Tristan d' Acuntia*. From thence Eastwards, the *Asian* South Pole (as I must take the liberty to call it) becoming prevalent, and the South point of the Needle being attracted thereby, there arises a West variation very great in quantity and extent, because of the great distance of this Magnetical Pole of the World. Hence it is, that in all the *Indian* Sea as far as *Hollandia Nova*, and farther, there is constantly West variation; at that under the Equator itself it arises to no less than eighteen Degrees, where 'tis most. About the Meridian of the Island *Celebes*, being likewise that of this Pole, this Westerly variation ceases, and an Easterly begins; which reaches, according to my Hypothesis, to the middle of the *South-Sea* between *Zelandia Nova* and *Chili*, leaving room for a small *West Variation* govern'd by the *American* South Pole, which I shew'd to be in the *Pacifick Sea*, in the sixth and seventh Remark.

What I have now said, does plainly shew the sufficiency of this Hypothesis for solving the variations that are at this time observ'd in the temperate and frigid *Zones*, where the direction of the Needle chiefly depends upon the Counterpoise of the forces of two Magnetical Poles of the same Nature; and I suppose I have shewn how it comes to pass, that under the same Meridian the variation should be in one place $29\frac{1}{2}$ West, and another $20\frac{1}{2}$ East; as I have noted in my ninth Remark.

In the *Torrid Zone*, and particularly under the Equinoctial, respect must be had to all four

Digitized by Google

Poles, and their Positions well consider'd, otherwise it will not be easie to determine what the variations shall be; the neareſt Pole being always the ſtrongeſt; yet not ſo, as not to be counterballanc'd ſometimes by the united forces of two more remote, a notable Inſtance whereof is in our eighth Remark, where I took notice, that in ſailing from St. *Helena* by the Iſle of *Aſcenſion*, to the Equator, on a *NW.* Courſe the variation is very little Eaſterly, and in that whole Tract unalterable; for which I give this Reaſon, that the South *American* Pole (which is conſiderably the neareſt in the aforeſaid places) requiring a great Eaſterly variation is counterpoiſed by the contrary Attraction of the *North-American* and the *Aſian-South* Pole; each whereof ſingly are in theſe parts, weaker than the *American-South-Pole*; and upon the *NW.* Courſe, the diſtance from this latter is very little varied; and as you recede from the *Aſian-South-Pole*, the ballance is ſtill preſerv'd by the acceſs towards the *North-American-Pole.* I mention not in this caſe the *European North-Pole*, its Meridian being little remov'd from thoſe of theſe places; and of it ſelf requiring the ſame variations we here find. After the ſame manner we might proceed to conclude the variations in other places under and near the Equator; but I purpoſely leave it for an exerciſe to the Thoughts of the ſerious Reader, who is deſir'd to help his Imagination, by having before him a Map or Globe of the Earth: And to mark thereon the Magnetical Poles in the *Longitudes* and *Latitudes* I aſſign them. (*Vide Plat.* 2.)

Thus

Digitized by Google

Thus, I hope, I have not lost my Pains and Study in this difficult Subject; believing that I have put it past doubt, *That there are in the Earth four such Magnetical Points or Poles which occasion the great variety and seeming irregularity which is observ'd in the variations of the Compass.* But to calculate exactly what it is, in any place assign'd, is what I dare not yet pretend to, tho' I could wish it were my happiness to be able to oblige the World with so useful a piece of Knowledge; there are difficulties that occur, that render the thing as yet not feasible, for first there are a great many Observations requisite, which ought to be made at the same time; not at Sea, but ashore, with greater Care and Attention than the generality of Sailors apply. And besides it remains undetermin'd in what proportion the attractive Power decreases, as you remove from the Pole of a Magnet, without which it were a vain attempt to go about to calculate. There is yet a further difficulty, which is the change of the variation, one of the discoveries of this last Century; which shews, that it will require some hundreds of Years to establish a compleat Doctrine of the Magnetical System. From the foregoing Table it should seem, that all the Magnetical Poles had a motion Westward: But if it be so, 'tis evident, that it is not a Rotation about the Axis of the Earth; for then the variations would continue the same, in the same parallel of *Latitude* (the *Longitude* only changed) as much as is the motion of the Magnetical Poles, but the contrary is found by Experience; for there is no where in the Latitude of $15\frac{1}{2}$ North between *England* and *America*, a variation of eleven Degrees East at this time;

as

Digitized by Google

as it was once here at *London*; it seems therefore, that our *European* Pole is grown nearer the Pole *Arctick* than it was heretofore, or else that it has lost part of its Vertue. But whether these Magnetical Poles move altogether with one motion, or with several; whether equally or unequally; whether Circular or Libratory: If Circular, about what Center; if Libratory, after what manner; are Secrets as yet utterly unkown to Mankind, and are reserv'd for the Industry of future Ages.

An

Digitized by Google

An Account of the Cauſe of the Change of the Variation of the Magnetical Needle, with an Hypotheſis of the Structure of the Internal parts of the Earth; as it was propoſed to the Royal Society *in one of their late Meetings.* By Mr. Edmund Halley.

HAving in the precedent Diſcourſe delivered a Theory of the Variation of the Magnetical Compaſs, wherein I did collect as many Obſervations as at that time I could procure, and having carefully compar'd them together, I came at length to this general concluſion, *That the Globe of the Earth might be ſuppoſed to be one great Magnet, having four Magnetical Poles or Points of Attraction, near each Pole of the Equator two; and that in thoſe parts of the World which lie near adjacent to any one of thoſe Magnetical Poles, the Needle is chiefly govern'd thereby; the neareſt Pole being always predominant over the more remote.* And I there have endeavour'd to ſtate and limit the preſent Poſition of thoſe Poles in the Surface of our Globe, which the Reader pleaſing to conſult will ſave us the pains of repeating. But after all, tho' that Diſcourſe was favourably receiv'd both at home and abroad, as ſeeming to render a tolerable account of the obſerv'd variations

Digitized by Google

variations, yet I found two difficulties not easie to surmount, the one was, that no Magnet I had ever seen or heard of, had more than two opposite Poles, whereas the Earth had visibly four, and perhaps more. And secondly, it was plain that these Poles were not, at least all of them, fixt in the Earth, but shifted from place to place, as appear'd by the great changes in the Needles direction within this last Century of Years, not only at *London*, (where this great Discovery was first made) but almost all over the Globe of Earth; whereas it is not known or observ'd that the Poles of a Load-stone ever shifted their place in the Stone, nor (considering the compact hardness of that substance) can it easily be suppos'd; tho' the matter of Fact be too notorious and universal, not to be accounted for.

These difficulties had wholly made me despond, and I had long since given over an Inquiry I had so little hopes of, when in accidental Discourse, and least expecting it, I stumbl'd on the following Hypothesis; in delivering whereof, if I shall seem to advance any thing that looks like Extravagant or Romantick, the Reader is desir'd to suspend his Censure, till he have consider'd the force and number of the many Arguments which concur to make good so new and so bold a Supposition.

Tho' it be sufficiently known and allow'd, that the Needles variation changes, it will be necessary however to give a few instances, whereby it may appear that this change is gradual and universal, and the effect of a great and permanent motion: For which take the following Examples.

At

Digitized by Google

At *London*, in the Year 1580, the variation was observ'd by Mr. *Burrows* to be 11° 15′ East. In *Anno* 1622, the same was found by Mr. *Gunter* to be but 6° 0′ East. In the Year 1634, Mr. *Gellibrand* found it 4°. 5′ East. In 1657, Mr. *Bond* observ'd that there was no variation at *London*. *Anno* 1672, my self observ'd it 2°. 30′ to the West; and in the Year 1692, I again found it 6° 00′ West. So that in 112 Years the direction of the Needle has chang'd no less than seventeen Degrees.

At *Paris*. *Orontius Finæus* about the Year 1550, did account it about eight or nine Degrees East variation. *Anno*. 1640, it was found three Degrees East. *Anno* 1666, there was no variation there, and *Anno* 1681, I found it to be 2° 30′ to the West.

At *Cap. d' Agulhas*, the most Southerly Promontary of *Africa*, about the Year 1600, the Needle pointed due North and South without variation, whence the *Portugueze* gave its name. *Anno* 1622, there was two Degrees West variation. *Anno* 1675, it was 8°. 00 West; and in the Year 1691, it was curiously observ'd not less than eleven Degrees West.

At St. *Helena*, about the Year 1600, the Needle declin'd eight Degrees to the East. *Anno* 1623, it was but 6°. 00′ East. *Anno* 1677, when I was there, I observ'd it accurately on Shoar to be 0*d*. 40′ East; and in 1692 it was found about 1 *d*. to the Westward of the North.

At *Cape Comorine* in *India*, in the Year 1620, there was 14 gr. 20′ West variation. In the Year 1680, there was 8°. 48′, but now lately in the Year 1688, it was no more than 7°. 30′, so that here the Needle has return'd to the East about seven Degrees in seventy Years. In

Digitized by Google

In all the other Examples the Needle has gradually mov'd towards the West, and the places are too far asunder to be influenc'd by the removal of any Magnetical Matter, which may by accident be transplac'd within the Bowels, or on the Surface of the Earth. If more Examples are desir'd, the Reader may be furnish'd with them in the *Portuguese Routier* of *Alexo de Motta* (written about the Year 1600) and in the Voyage of *Beaulieu*, both publish'd in Mr. *Thevenot*'s first Collection of curious Voyages, Printed at *Paris*, *Anno* 1663; which he is to compare with the Journals of our late *East India* Voyagers, and I am assur'd, that it will be thereby evident, that the direction of the Needle is in no place fix'd and constant, tho' in some it change faster than in others: And where for a long time it has continu'd as it were unalter'd, it is there to be understood, that the Needle has its greatest Deflection, and is become Stationary in order to return, like the Sun, in the Tropick. This, at present, is in the *Indian-Sea*, about the Island *Mauritius*, where is the highest West variation, and in a Tract tending from thence into the N. N. W. towards the *Red-Sea* and *Egypt*. And in all Places to the Westward of this Tract, all over *Africa* and the Seas adjoining, the West variation will be found to have encreas'd; and to the Eastwards thereof, as in the Example of *Cape Comorine*, to have decreas'd, *viz.* all over the *East-Indies* and the Islands near it.

After the like manner in that Space of East variation, which, beginning near St. *Helena*, is found all over the South *America*, and which at present is highest about the Mouth of *Rio de la Plata*, it has been observ'd, that in the Eastern

Parts

Parts thereof, the variation of the Needle gradually decreases; but whether on the contrary it increases in those places which lie more Westerly than that Tract wherein the highest East variation is found; or how it may be in the vast *Pacifick-Sea*, we have not Experience enough to ascertain, only we may by Analogy infer, that both the East and West variations therein do gradually increase and decrease after the same Rule.

These *Phænomena* being well understood and duly consider'd, do sufficiently evince, That the whole Magnetical System is by one, or perhaps more motions translated, whether Eastwards or Westwards, I shall anon discuss; that this moving thing is very great, as extending its effects from Pole to Pole; and that the motion thereof it not *per saltum*, but a gradual and regular motion.

Now considering the Structure of our *Terraqueous* Globe, it cannot be well suppos'd that a very great part thereof can move within it, without notably changing its Center of Gravity and the Equilibre of its Parts, which would produce very wonderful Effects in changing the Axis of diurnal Rotation, and occasion strange alteration in the Seas Surface, by Inundations and Recesses thereof, such as History never yet mention'd. Besides, the solid parts of the Earth are not to be granted permeable by any other than fluid Substances, of which we know none that are any ways Magnetical. So that the only way to render this motion intelligible and possible, is, to suppose it to turn about the Center of the Globe, having its Center of Gravity fix'd and immoveable in the same common Center of the Earth: And there is yet requir'd,

that

Digitized by Google

that this moving internal Substance be loose and detached from the external Parts of the Earth whereon we live; for otherwise were it affix'd thereto, the whole must necessarily move together.

So then the External Parts of the Globe may well be reckon'd as the Shell, and the Internal as a *Nucleus* or inner Globe included within ours, with a fluid medium between, which having the same common Center and Axis of diurnal Rotation, may turn about with our Earth each twenty four Hours; only this outer Sphere having its turbinating motion some small matter either swifter or slower than the internal Ball: And a very Minute difference in length of time, by many repetitions becoming sensible, the Internal Parts will by degrees recede from the External, and not keeping pace with one another will appear gradually to move either Eastwards or Westwards by the difference of their motions.

Now supposing such an Internal Sphere having such a motion, we shall solve the two great Difficulties we encounter'd in my former Hypothesis: For if this exterior Shell of Earth be a Magnet having its Poles at a distance from the Poles of diurnal Rotation; and if the Internal *Nucleus* be likewise a Magnet, having its Poles in two other places distant also from the Axis; and these latter by a gradual and slow motion change their place in respect of the External; we may then give a reasonable account of the four Magnetical Poles I presume to have demonstrated before; as likewise of the changes of the Needles variations, which till now hath been unattempted.

The

The Period of this motion being wonderful great, and there being hardly an hundred Years ſince theſe Variations have been duly obſerv'd, it will be very hard to bring this Hypotheſis to a Calculus, eſpecially ſince, tho' the Variations do increaſe and decreaſe regularly in the ſame place, yet in differing places, at no great diſtance, there are found ſuch caſual Changes thereof as can no ways be accounted for by a regular Hypotheſis; as depending upon the unequal and irregular diſtribution of the Magnetical Matter within the ſubſtance of the external Shell or Coat of the Earth, which deflect the Needle from the Poſition it would acquire from the effect of the general Magnetiſm of the whole. Of this the Variations at *London* and *Paris* give a notable inſtance, for the Needle has been conſtantly about $1^{\circ}\frac{1}{2}$ more Eaſterly at *Paris* than at *London*; tho' it be certain that according to the general effect, the difference ought to be the contrary way: Notwithſtanding which the Variations in both places do change alike.

Hence, and from ſome other of like Nature, I conclude, That the two Poles of the external Globe are fixt in the Earth, and that if the Needle were wholly govern'd by them, the Variations thereof would be always the ſame, with ſome little Irregularities upon the account I but juſt now mention'd: But the internal Sphere having ſuch a gradual tranſlation of its Poles, does influence the Needle, and direct it variouſly according to the reſult of the attractive or directive Power of each Pole; and conſequently there muſt be a Period of the Revolution of this internal Ball, after which the Variations will return again as before. But if it

Digitized by Google

ſhall in future Ages be obſerv'd otherwiſe, we muſt then conclude that there are more of theſe Internal Spheres, and more Magnetical Poles than Four, which at preſent we have not a ſufficient number of Obſervations to determine, and particularly in that vaſt *Mar del Zur*, which occupies ſo great a part of the whole Surface of the Earth.

If then two of the Poles be fixt and two moveable, it remains to aſcertain which they are that keep their place; and tho' I could wiſh we had the experience of another Century of Years to found our Concluſions upon, yet I think we may ſafely determine, *That our European North Pole* (which in the precedent Diſcourſe I ſuppos'd near the Meridian of the Lands end of *England*, and about 7 Degrees therefrom) is that That is moveable of the two Northern Poles, and that That has chiefly influenc'd the Variations in theſe parts of the World: For in *Hudſon*'s Bay, which is under the Direction of the *American* Pole, the change is not obſerv'd to be near ſo faſt as in theſe parts of *Europe*, tho' that Pole be much farther remov'd from the Axis.

As to the *South Poles*, I take the *Aſian* Pole, which I place about the Meridian of the Iſland *Celebes* to be the fixt, and conſequently the *American* Pole to move; from the like Obſervation of the ſlow Decreaſe of the Variation on the Coaſt of *Java*, and near the Meridian of the *Aſian* Pole; tho' I muſt confeſs to have no account of the effects of the other beyond *Magellan*'s Streights.

If this be allow'd me, 'tis plain that the fixt Poles are the Poles of this External Shell or Cortex of the *Earth*, and the other two the Poles of a Magnetical *Nucleus* included and moveable

Digitized by Google

moveable within the other. It likewiſe follows, that this Motion is Weſtwards, and by conſequence that the aforeſaid *Nucleus* has not preciſely attained the ſame degree of Velocity with the exteriour Parts in their diurnal Revolution; but ſo very nearly equals it, that in 365 Revolves the difference is ſcarce ſenſible. This I conceive to ariſe from the Impulſe whereby this diurnal Motion was impreſt on the Earth, being given to the external Parts, and from thence in time communicated to the Internal; but not ſo as perfectly to equal the Velocity of the firſt Motion impreſs'd on, and ſtill conſerv'd by the ſuperficial Parts of the Globe.

As to the Quantity of this Motion it is almoſt impoſſible to define it, both from the Nature of this kind of Obſervation, which cannot be very accurately perform'd, as alſo from the ſmall time theſe Variations have been obſerv'd, and their change diſcover'd. It appears by all Circumſtances, that its Period is of many Centuries of Years, and as far as may be collected from the Change of the Place, where there was no Variation by reaſon of the Equilibre of the two Southern Magnetical Poles, *viz.* from *Cape d' Agulhas* to the Meridian of St. *Helena* (which is about 23gr in about ninty Years) and of the place where the Weſterly Variation is in its ἀκμὴ, or greateſt Deflection, being about half ſo much, *viz.* from the Iſle of *Diego Roiz* to the South Weſt Parts of *Madagaſcar*. We may with ſome Reaſon conjecture, that the *American* Pole has mov'd Weſtwards fourty ſix Degrees in that time, and that the whole Period thereof is perform'd in ſeven hundred Years, or thereabouts; ſo that the nice Determination of this and of ſeveral other particulars in the

Digitized by Google

Magnetick Syſtem is reſerv'd for remote Poſterity; all that we can hope to do, is to leave behind us Obſervations that may be confided in, and to propoſe Hypotheſis which after Ages may examine, amend or refute. Only here I muſt take leave to recommend to all Maſters of Ships and all others, Lovers of Natural Truths, that they uſe their utmoſt Diligence to make, or procure to be made, Obſervations of theſe Variations in all parts of the World, as well in the North as South Latitude (after the laudable Cuſtom of our *Eaſt-India* Commanders) and that they pleaſe to communicate them to the *Royal Society*, in order to leave as compleat a Hiſtory as may be to thoſe that are hereafter to compare all together, and to compleat and perfect this abſtruſe Theory.

And by the way it will not be amiſs to amend a receiv'd Error in the Practice of obſerving the Variation, which is, to take it by the Amplitude of the Riſing and Setting Sun, when his Center appears in the viſible Horizon; whereas he ought to be obſerv'd when his under Limb is ſtill above the Horizon about $\frac{2}{3}$ of his Diameter, or twenty Minutes, upon the ſcore of the Refraction, and the height of the Eye of the Obſerver above the Surface of the Sea: Or elſe they are to work the Amplitudes as they do the Azimuth, reckoning the Suns diſtance from the Zenith 90°. 36′: This, tho' it be of little conſequence near the Æquinoctial, will make a great error in high Latitudes, where the Sun riſes and ſets obliquely.

But to return to our Hypotheſis, In order to explain the change of the Variations, we have adventur'd to make the Earth hollow and to place

Digitized by Google

place another Globe within it; and I doubt not but this will find Oppoſers enough. I know 'twill be Objected, That there is no Inſtance in Nature of the like thing; that if there was ſuch a middle Globe it would not keep its place in the Centre, but be apt to deviate there-from, and might poſſibly chock againſt the Concave Shell, to the ruine, or at leaſt endammaging thereof; That the Water of the Sea would perpetually leak through, unleſs we ſuppoſe the Cavity full of Water; That were it poſſible, yet it does not appear of what uſe ſuch an inward Sphere can be of, being ſhut up in eternal Darkneſs, and therefore unfit for the Production of Animals or Plants; with many more Objections, according to the Fate of all ſuch new Propoſitions.

To theſe, and all other that I can foreſee, I briefly Anſwer, That the Ring environing the Globe of *Saturn* is a notable Inſtance of this kind, as having the ſame common Center, and moving along with the Planet, without ſenſibly approachihg him on one ſide more than the other. And if this Ring were turn'd on one of its Diameters, it would then deſcribe ſuch a Concave Sphere as I ſuppoſe our External one to be. And ſince the Ring, in any Poſition given, would, in the ſame manner, keep the Centre of *Saturn* in its own, it follows, that ſuch a Concave Sphere may move with another included in it, having the ſame common Centre. Nor can it well be ſuppos'd otherwiſe, conſidering the Nature of Gravity; for ſhould theſe Globes be adjuſted once to the ſame common Centre, the Gravity of the parts of the Concave would preſs equally towards the Centre of the inner Ball, which equality muſt neceſ-

Digitized by Google

sarily continue till some external Force disturb it, which is not easie to imagine in our case. This perhaps I might more intelligibly express, by saying that the inner Globe being posited in the Centre of the Exterior, must necessarily ascend which way soever it move; that is, it must overcome the force of Gravity pressing towards the common Centre, by an impulse it must receive from some outward Agent; but all outward Efforts being sufficiently fenc'd against by the Shell that surrounds it, it follows, that this *Nucleus* being once fixt in the common Centre, must alwas there remain.

As to the leaking of the Water through this Shell, when once a passage shall be found for it to run through, I must confess it is an Objection seemingly of weight; but when we consider how tightly great Beds of Chalk or Clay, and much more Stone do hold Water, and even Caves arch'd with Sand; no Man can doubt but the Wisdom of the Creator has provided for the Macrocosm by many more ways than I can either imagine or express, especially since we see the admirable and innumerable Contrivances wherewith each worthless Individual is furnish'd both to defend itself and propagate its Species. What Curiosity in the Structure, what Accuracy in the Mixture and Composition of the parts ought not we to expect in the Fabrick of this Globe, made to be the lasting Habitation of so many various Species of Animals, in each of which there want not many Instances that manifest the boundless Power and Goodness of their Divine Author; and can we then think it a hard supposition that the Internal Parts of this Bubble of Earth should be replete with such Saline and Vitriolick Particles as may contribute

Digitized by Google

tribute to Petrifaction, and dispose the transuding Water to shoot and coagulate into Stone, so as continually to fortifie, and, if need were, to consolidate any breach or flaw in the Concave surface of the Shell.

And this perhaps may not without reason be suppos'd to be the final Cause of the admixture of the Magnetical Matter in the Mass of the Terrestial parts of our Globe, *viz.* To make good and maintain the Concave Arch of this Shell: For by what the excellent Mr. *Newton* has shewn in his *Principia Philosophiæ*, it will follow, that according to the general Principle of Gravity, visible throughout the whole Universe, all those Particles that by length of time or otherwise, shall moulder away or become loose on the Concave Surface of the External Sphere, would fall in, and with great force descend on the Internal, unless those Particles were of another sort of Matter capable by their stronger tendency to each other, to suspend the force of Gravity; but we know no other Substances capable of supporting each other by their mutual Attraction but the Magnetical, and these we see miraculously to perform that Office, even where the Power of Gravity has its full effect, much more within the Globe where it is weaker. Why then may we not suppose these said Arches to be lin'd throughout with a Magnetical Matter, or rather to be one great Concave Magnet, whose two Poles are the Poles we have before observ'd to be fixt in the Surface of our Globe.

Another Argument, favouring this Hypothesis, is drawn from a Proposition of the same Mr. *Newton*, where he determines the force wherewith the *Moon* moves the *Sea* in produc-

Digitized by Google

ing the *Tides*; His words are, *Denſitas Lunæ eſt ad denſitatem Terræ ut* 680 *ad* 387 *ſeu* 9 *ad* 5 *quamproxime. Eſt igitur corpus Lunæ denſius ac magis tereſtre quam Terra noſtra*, p. 466. Now if the Moon be more ſolid than the Earth, as 9 to 5, why may we not reaſonably ſuppoſe the Moon, being a ſmall Body and a Secondary Planet, to be ſolid Earth, Water, Stone, and this Globe to conſiſt of the ſame Materials, only four Ninths thereof to be Cavity, within and between the internal Spheres; which I would render not improbable.

To thoſe that ſhall enquire of what uſe theſe included Globes can be, it muſt be allow'd, that they can be of very little ſervice to the Inhabitants of this outward World, nor can the Sun be ſerviceable to them, either with his Light or Heat. But ſince it is now taken for granted, that the Earth is one of the Planets, and they all are with reaſon ſuppos'd Habitable, though we are not able to define by what ſort of Animals; and ſince we ſee all the parts of the Creation abound with Animate Beings, as the Air with Birds and Flies, the Water with the numerous varieties of Fiſh, and the very Earth with Reptiles of ſo many ſorts; all whoſe ways of Living would be to us incredible did not daily Experience teach us. Why then ſhould we think it ſtrange that the prodigious Maſs of Matter, whereof this Globe does conſiſt, ſhould be capable of ſome other improvement than barely to ſerve to ſupport its Surface? Why may not we rather ſuppoſe that the excceding ſmall quantity of ſolid Matter in reſpect of the fluid Æther, is ſo diſpos'd by the Almighty Wiſdom, as to yield as great a Surface for the uſe of living Creatures, as can conſiſt

Digitized by Google

sist with the conveniency and security of the whole? We our selves, in Cities where we are pressed for room, commonly build many Stories one over the other, and thereby accommodate a much greater multitude of Inhabitants.

But still it will be said, that without Light there can be no living, and therefore all this *apparatus* of our inward Globes must be useless: To this I Answer, That there are many ways of producing Light which we are wholly ignorant of; the Medium itself may be always luminous after the manner of our *Ignes fatui*. The Concave Arches may in several places shine with such a Substance as invests the Surface of the Sun; nor can we, without a boldness unbecoming a Philosopher, adventure to assert the impossibility of peculiar Luminaries below, of which we have no sort of *Idea*. I am sure the Poets *Virgil* and *Claudian* have gone before me in this Thought, inlightning their *Elysian Fields* with Sun and Stars proper to those infernal, or rather internal, Regions. *Virg. Æneid. 6.*

Largior hic campos Æther & lumine vestit.
Purpureo; Solemque suum sua Sidera norunt.

And *Claudian* lib. 2. *De Raptu Proserpinæ.*

Amissum ne crede diem, sunt altera nobis
Sidera, sunt orbes alii, lumenque videbis
Purius, Elysiumque magis mirabere Solem.

And tho' this be not to be esteem'd as an Argument, yet I may take the liberty I see others do; to quote the Poets when it makes for my purpose.

Lastly,

Digitized by Google

Lastly, To explain yet farther what I mean, I have adventur'd to adjoin the following Scheme, (*Table* 1. *Fig.* 3.) wherein the Earth is represented by the outward Circle, and the three inward Circles are made nearly proportionable to the Magnitudes of the Planets *Venus*, *Mars* and *Mercury*, all which may be included within the Globe of Earth, and all the Arches more than sufficiently strong to bear their weight. The Concave of each Arch, which is shaded differently from the rest, I suppose to be made up of Magnetical Matter; and the whole to turn about the same common Axis *p*, *p*, only with this difference, that the Outer Sphere still moves somewhat faster than the Inner. Thus the Diameter of the Earth being about eight thousand *English* Miles, I allow five hundred Miles for the thickness of its Shell, and another space of five hundred Miles for a Medium between, capable of an immense Atmosphere for the use of the Globe of *Venus*: *Venus* again I give a Shell of the same thickness, and leave as great a space between her Concave and *Mars*; so likewise from *Mars* to *Mercury*, which latter Ball we will suppose solid, and about two thousand Miles Diameter. Thus I have shew'd a possibility of a much more ample Creation, than has hitherto been imagin'd; and if this seem strange to those that are unaquainted with the Magnetical System, it is hop'd that all such will endeavour, first, to inform themselves of the Matter of Fact, and then try if they can find out a more simple Hypothesis, at least a less absurd, even in their own Opinions. And whereas I have adventur'd to make these Subterraneous Orbs capable of being Inhabited, 'twas done designedly for the sake of those who will be apt to

Digitized by Google

to ask *cui bono*, and with whom Arguments drawn from *Final Cauſes* prevail much. If this ſhort Eſſay ſhall find a kind acceptance, I ſhall be encourag'd to enquire farther, and to Poliſh this rough Draft of a Notion till hitherto not ſo much as ſtarted in the World, and of which we could have no Intimation from any other of the *Phænomena* of Nature.

Since this was written, a Diſcovery I have made in the Celeſtial Motions, ſeems to render a farther account of the Uſe of the Cavity of the Earth, *viz.*, To diminiſh the Specifick Gravity thereof in reſpect of the Moon; for I *think* I can demonſtrate *that the Oppoſition of the Æther to the Motions of the Planets in* long time becomes ſenſible; and conſequently the greater Body muſt receive a leſs Oppoſition than the ſmaller, unleſs the Specifick Gravity of the ſmaller do proportionably exceed that of the greater, in which caſe only they can move together; ſo that the Cavity I aſſign in the Earth, may well ſerve to adjuſt its weight to that of the Moon; for otherwiſe the Earth would leave the Moon behind it, and ſhe become another Primary Planet.

An

Digitized by Google

Digitized by Google

An Historical Account of the Trade Winds *and* Monsoons, *observable in the Seas between and near the* Tropicks, *with an attempt to assign the Physical Cause of the said Winds, by Mr.* Ed. Halley.

AN exact Relation of the constant and Periodical Winds, observable in several Tracts of the Ocean, is a part of Natural History not less desireable and useful, than it is difficult to obtain, and its *Phænomena* hard to explicate: I am not ignorant that several Writers have undertaken this Subject, and altho' *Varenius* (*Lib.* 1. *Chap.* 21. *Geo. Gen.*) seems to have endeavour'd after the best information from *Voyagers*, yet cannot his accounts be admitted for accurate, by those that shall attentively consider and compare them together, and some of them are most evident mistakes; which, as near as I can, I shall attempt to rectify, having had the opportunity of conversing with Navigators acquainted with all parts of *India*, and having liv'd a considerable time between the *Tropicks*, and there made my own Remarks.

The Substance of what I have collected is briefly as follows.

The Universal *Ocean* may most properly be divided into three Parts, *viz.* 1. The *Atlantick* and *Æthiopick-Sea.* 2. The The *Indian Ocean.* 3. The

Digitized by Google

3. The Great *South Sea*, or the *Pacifick Ocean*; and tho' these Seas do all communicate by the South, yet as to our present purpose of the *Trade Winds*, they are sufficiently seperated by the interposition of great Tracts of *Land*; the first lying between *Africa* and *America*, the second between *Africa*, and the *Indian Islands* and *Hollandia Nova*; and the last between the *Philippine Isles*, *China*, *Japan* and *Hollandia Nova* on the *West*, and the Coast of *America* on the *East*. Now following this natural division of the Seas, so will we divide our History into three parts in the same order.

I. In the *Atlantick* and *Æthiopick* Seas between the *Tropicks*, there is a general *Easterly Wind*, all the Year long, without any considerable Variation, excepting that it is subject to be deflected there-from, some few Points of the Compass towards the *North* or *South*, according to the Position of the place. The Observations which have been made of these Deflections, are the following.

1. That near the Coast of *Africa*, as soon as you have pass'd the *Canary Isles* you are sure to meet a fresh Gale of *N. E.* Wind about the Latitude of 28 Degrees *North*, which seldom comes to the *Eastwards* of the *E. N. E.* or passes the *N. N. E.* This Wind accompanies those bound to the Southward, to the Latitude of ten North, and about a hundred Leagues from the *Guinea* Coast, where, till the fourth Degree of North Latitude, they fall into the Calmes and Tornadoes, of which more hereafter.

2. That

Digitized by Google

2. That thoſe bound to the *Caribbe Iſles*, find, as they approach the *American* ſide, that the afore-ſaid North-East Wind, becomes ſtill more and more Eaſterly, ſo as ſometimes to be East, ſometimes East by South, but yet moſt commonly to the Northward of the East a Point or two, ſeldom more. 'Tis likewiſe obſerv'd, that the ſtrength of theſe Winds does gradually decreaſe, as you ſail to the Weſtwards.

3. That the limits of the Trade and variable Winds, in this Ocean, are farther extended on the *American* ſide than the *African*; for whereas you meet not with this certain Wind till after you have paſs'd the Latitude of twenty eight degrees on this ſide; on the *American* ſide it commonly holds to thirty, thirty one, or thirty two degrees of Latitude; and this is verified likewiſe to the Southwards of the Æquinoctial, for near the *Cape* of *Good-Hope* the limits of the Trade Winds, are three or four Degrees nearer the Line, than on the Coaſt of *Brazile*.

4. That from the Latitude of four Degrees North, to the afore-ſaid Limits on the South of the Æquator, the Winds are generally and perpetually between the South and Eaſt, and moſt commonly between the South-East and East, obſerving always this Rule, that on the *African* ſide they are more Southerly, on the *Braſilian* more Eaſterly, ſo as to become almoſt due East, the little deflection they have being ſtill to the Southwards. In this part of the Ocean it has been my fortune to paſs a full Year, in an Employment that oblig'd me to regard more than ordinary the Weather, and I found the Winds conſtantly about the South-East, the moſt uſual Point *S E b E*; when it was

was Eaſterly it generally blew hard, and was gloomy, dark, and ſometimes rainy Weather; if it came to the Southwards it was generally Serene, and a ſmall Gale next to a Calm, but this not very common. But I never ſaw it to the Weſtwards of the South, or Northwards of the Eaſt.

5. That the Seaſon of the Year has ſome ſmall effect on theſe Trade Winds, for that when the Sun is conſiderable to the Northwards of the Equator, the South-Eaſt Winds, eſpecially in the Straight of this Ocean (if I may ſo call it) between *Braſile* and the Coaſt of *Guinea*, do vary a Point or two to the Southwards, and the North-Eaſt become more Eaſterly; and on the contrary, when the Sun is towards the Tropick of *Capricorn* the South-Eaſterly Winds become more Eaſterly, and the North-Eaſterly Winds on this ſide the Line vere more to the Northwards.

6. That as there is no general Rule that admits not of ſome exception, ſo there is in this Ocean a Tract of Sea wherein the Southerly and South-Weſt Winds are perpetual, *viz.* all along the Coaſt of *Guinea*, for above five hundred Leagues together, from *Sierra Leona* to the Iſle of St. *Thomas*; for the South-Eaſt Trade Wind having paſs'd the Line, and approaching the Coaſt of *Guinea* within eighty or 100 Leagues inclines towards the Shore and becomes S. S. E., and by Degrees, as you come nearer, it veres about to South, S. S. Weſt, and in with the Land South-Weſt, and ſometimes Weſt South-Weſt; which Variation is better expreſs'd in the Mapp hereto annexed, (*Vide Plate* 2.) than it can well be in words. Theſe are the Winds which are obſery'd on this Coaſt when it blows

Digitized by Google

blows true, but there are frequent Calms, Violent suddain Gusts call'd *Tornado's*, from all Points of the Compass, and sometimes unwholsome foggy Easterly Winds call'd *Hermitaa* by the Natives, which too often infest the Navigation of these parts.

7. That to the Northwards of the Line, between four and ten Degrees of Latitude, and between the Meridians of *Cape Virde*, and of the Eastermost Islands that bear that Name, there is a Tract of Sea wherein it were improper to say there is any Trade Wind, or yet a Variable; for it seems condemn'd to perpetual Calms, attended with terrible Thunder and Lightning, and Rains so frequent, that our Navigators from thence call this part of the Sea the *Rains*; the little Winds that are, be only some suddain uncertain Gusts, of very little continuance and less extent; so that sometimes each hour you shall have a different Gale, which dies away into a Calm before another succeed, and in a Fleet of Ships in sight of one another, each shall have the Wind from a several Point of the Compass; with these weak *Brizes* Ships are oblig'd to make the best of their way to the Southward through the afore-said six Degrees, wherein 'tis reported some have been detain'd whole Months for want of Wind.

From the three last observables is shewn the Reason of two notable Occurents in the *East-India* and *Guinea* Navigations: The one is, why, notwithstanding the narrowest part of the Sea between *Guinea* and *Brasile* be about five hundred Leagues over, yet Ships bound to the Southward sometimes, especially in the Months of *July* and *August*, find a great difficulty to pass it. This happens because of the South-

Digitized by Google

Eaſt Winds, at that time of the Year commonly extending ſome Degrees beyond the ordinary limit of four Degrees North Latitude, and withal they come ſo much Southerly, as to be ſometimes South, ſometimes a Point or two to the Weſt; there remains then only to ply to Wind-ward, and if on the one ſide they ſtand away W. S. W. they gain the Wind ſtill more and more Eaſterly, but there is danger of not weathering the *Braſilian* Shore, or at leaſt the Shoals upon that Coaſt. But if upon the other Tack they go away E. S. E. they fall into the Neighbourhood of the Coaſt of *Guinea*, from which there is no departing without running Eaſterly, as far as the Iſle of St. *Thomas*, which is the conſtant practiſe of all the *Guiny* Ships, and which may ſeem very ſtrange without the conſideration of the fifth Remark, which ſhews the reaſon of it: For being in with the Coaſt, the Wind blows generally at S. W. and W. S. W. with which Winds they cannot go to the Northward for the Land, and on the other Tack they can lie no nearer the Wind than S. S. E. or South; with theſe Courſes they run off the Shore, but in ſo doing they always find the Winds more and more contrary; ſo that when near the Shore they could lie South, at a greater diſtance they can make their way no better than S. E. and afterwards E. S. E. with which courſes they fetch commonly the Iſle of St. *Thomas* and Cape *Lopez*, where finding the Winds to the Eaſtward of the South, they keep them favourable by running away to the Weſtward in the South Latitude, of three or four Degrees, where the S. E. Winds are perpetual.

For the ſake of theſe general Winds, all

Digitized by Google

thoſe that uſe the *Weſt-Indian* Trade, even thoſe bound to *Virginia*, count it their beſt courſe to get as ſoon as they can to the Southwards, that ſo they may be certain of a fair and freſh Gale to run before it to the Weſtwards; and for the ſame reaſon thoſe homewards bound from *America*, endeavour to gain the Latitude of thirty Degrees, as ſoon as poſſible, where they firſt find the Winds begin to be Variable; though the moſt ordinary Winds in the Northern part of the *Atlantick* Ocean come from between the South and Weſt.

As to thoſe furious Storms call'd *Hurricanes*, which are, as it were, peculiar to the *Caribbe* Iſles; and which ſo dreadfully afflict them in the Month of *Auguſt*, or not much before or after, they do not ſo properly belong to this place, both by reaſon of their ſmall continuance and extent, as likewiſe becauſe they are not Anniverſary, ſome Years having more than one, and ſometimes for ſeveral Years together there being none at all. But their Violence is ſo unconceivable, and their other *Phænomena* ſo ſurpriſing, that they merit well to be conſider'd apart.

What is here ſaid, is to be underſtood of the Sea Winds at ſome diſtance from the Land; for upon and near the Shores, the Land and Sea Brizes are almoſt every where ſenſible; and the great Variety which happens in their Periods, Force and Direction, from the ſituation of the Mountains, Vallies and Woods, and from the various Texture of the Soil, more or leſs capable of retaining and reflecting Heat, and of exhaling or condenſing Vapours is ſuch, that it were an endleſs task, to endeavour to account for them.

Digitized by Google

II. In the *Indian* Ocean, the Winds are partly general, as in the *Æthiopick* Ocean, partly Periodical, that is, half the Year they blow one way, and the other half near upon the oppoſite Points; and theſe Points and Times of ſhifting are diffeent in different parts of this Ocean; the limits of each tract of Sea, ſubject to the ſame change or *Monſoon*, are certainly very hard to determine, but the diligence I have uſed to be rightly inform'd, and the care I have taken therein, has, in a great meaſure, ſurmounted that difficulty, and I am perſwaded that the following particulars may be relied upon.

1. That between the Latitudes of ten Degrees and thirty Degrees South, between *Madagaſcar* and *Hollandia Nova*, the general Trade Wind about the S. E. by E. is found to blow all the Year long, to all Intents and Purpoſes after the ſame manner as in the ſame Latitudes in the *Æthiopick* Ocean, as it is deſcribed in the fourth *Remark* aforeging.

2. That the aforeſaid S. E. Winds extend to within two Degrees of the *Æquator*, during the Months of *June*, *July*, *Auguſt*, &c. to *November*, at which time between the *South Latitudes* of three and ten Degrees, being near the Meridian of the North end of *Madagaſcar*, and between two and twelve South Latitude, being near *Sumatra* and *Java*, the contrary Winds from the N. W. or between the *North* and Weſt, ſet in and blow for half the Year, *viz.* from the beginning of *December* till *May*; and this *Monſoon* is obſerv'd as far as the *Molucca* Iſles, of which more anon.

3. That

Digitized by Google

3. That to the Northward of three Degrees South Latitude, over the whole *Arabian* or *Indian-Sea* and Gulph of *Bengall*, from *Sumatra* to the Coaſt of *Africa*, there is another *Monſoon*, blowing from *October* to *April* upon the North Eaſt Points; but in the other half Year, from *April* to *October*, upon the oppoſite Points of S. W. and W. S. W. and that with rather more force than the other accompanied with dark rainy Weather, whereas the N. E. blows clear; 'tis likewiſe to be noted, that the Winds are not ſo conſtant, either in ſtrength or point in the Gulph of *Bengall*, as they are in the *Indian-Sea*, where a certain and ſteady Gale ſcarce ever fails. 'Tis alſo remarkable, that the S. W. Winds in theſe Seas are generally more Southerly on the *African* ſide, more Weſterly on the *Indian*.

4. That as an *Appendix* to the laſt deſcribed *Monſoon*, there is a Tract of Sea to the Southwards of the Æquator, ſubject to the ſame changes of the Winds, *viz.* near the *African* Coaſt, between it and the Iſland *Madagaſcar* or St. *Laurence*, and from thence Northwards as far as the Line; wherein from *April* to *October* there is found a conſtant freſh S. S. W. Wind, which, as you go more Northerly, becomes ſtill more and more Weſterly, ſo as to fall in with the W. S. W. Winds, mention'd before, in thoſe Months of the Year to be certain to the Northward of the Æquator: What Winds blow in theſe Seas, for the other half Year, from *October* to *April*, I have not yet been able to obtain to my full ſatisfaction, for that our Navigators always return from *India* without *Madagaſcar*, and ſo are little acquainted in this matter; the Account that has been given me is

Digitized by Google

only this, that the Winds are much Easterly hereabouts, and as often to the North of the true East as to the Southwards thereof.

5. That to the Eastward of *Sumatra* and *Malacca*, to the Northwards of the Line, and along the Coast of *Camboia* and *China*, the *Monsoons* blow North and South, that is to say, the N. E. Winds are much Northerly, and the S. W. much Southerly: This Constitution reaches to the Eastwards of the *Philippine*-Isles, and as far Northerly as *Japan*. The Northern *Monsoon* setting in, in these Seas, in *October* or *November*, and the Southern in *May*, blowing all the Summer Months: Here it is to be noted, That the Points of the Compass, from whence the Wind comes in these Parts of the World, are not so fixt as in those lately describ'd; for the Southerly will frequently pass a Point or two to the Eastwards of the South, and the Northerly as much to the Westwards of the North, which seems occasion'd by the great quantity of Land which is interspers'd in these Seas.

6. That in the same *Meridians*, but to the Southwards of the Equator, being that Tract lying between *Sumatra* and *Java* to the West, and New *Guinea* to the East, the same Northerly *Monsoons* are observ'd, but with this difference, that the inclination of the Northerly is towards the N. W. and of the Southerly towards the S. E. but the *plaga venti* are not more constant here than in the former, *viz.* variable five or six Points; besides the times of the Change of these Winds, are not the same as in the *Chinese* Seas, but about a Month or six Weeks later.

7. That

Digitized by Google

7. That these contrary Winds do not shift all at once, but in some places the time of the change is attended with Calms, in others with variable Winds; and it is particularly remarkable, that the end of the Westerly *Monsoon* on the Coast of *Coromandel*, and the two last Months of the Southerly *Monsoon* in the Seas of *China* are very subject to be tempestuous: The violence of these Storms is such, that they seem to be of the Nature of the *West-India Hurricanes*, and render the Navigation of these parts very unsafe about that time of the Year. These Tempests are by our Seamen usually term'd, *The breaking up of the Monsoons.*

By reason of the shifting of these Winds, all those that sail in these Seas, are oblig'd to observe the Seasons proper for their Voyages, and so doing they fail not of a fair Wind and speedy Passage; but if so be they chance to out-stay their time till the contrary *Monsoon* set in, as it frequently happens, they are forc'd to give over the hopes of accomplishing their intended Voyages, and either return to the Port from whence they came, or else put in to some other Harbour, there to spend the time till the Winds shall come favourable.

III. The third Ocean call'd *Mare Pacificum*, whose extent is equal to that of the other two (it being from the West Coast of *America* to the *Philippine* Islands, not less than 150 Degrees of Longitude) is that which is least known to our own or the Neighbour Nations; that Navigation that there is on it, is by the *Spaniards*, who go Yearly from the Coast of New *Spain* to the *Manilha's*, but that but by one beaten track; so that I cannot be so particular here as in the o-

Digitized by Google

ther two. What the *Spaniſh* Authors ſay of the Winds they find in their Courſes, and what is confirm'd by the old Accounts of *Drake* and *Candiſh*, and ſince by *Schooten*, who ſail'd the whole breadth of this Sea in the Southern Latitude of fifteen or ſixteen Degrees, is, that there is a great conformity between the Winds of this Sea, and thoſe of the *Atlantick* and *Æthiopick*; that is to ſay, that to the Northwards of the Æquator, the predominant Wind is between the Eaſt and North-Eaſt, and to the Southwards thereof there is a conſtant ſteady Gale between the Eaſt and South-Eaſt, and that on both ſides the Line with ſo much conſtancy, that they ſcarce ever need to attend the Sails, and Strength, that it is rare to fail of croſſing this vaſt Ocean in ten Weeks time, which is about 130 Miles *per diem*; beſides 'tis ſaid that Storms and Tempeſts are never known in theſe parts: So that here is the very beſt of Sailing; no want of a freſh fair Wind, and yet no danger of having too much: Wherefore ſome have thought it might be as ſhort a Voyage to *Japan* and *China*, to go by the Streights of *Magellan*, as by the *Cape* of *Good-Hope*.

The limits of theſe general Winds are alſo much the ſame as in the *Atlantick* Sea, *viz.* about the thirtieth Degree of Latitude on both ſides; for the *Spaniards* homewards bound from the *Manhila*'s, always take the advantage of the Southerly *Monſoon*, blowing there in the Summer Months, and run up to the Northwards of that Latitude, as high as *Japan*, before they meet with variable Winds, to ſhape their Courſe to the Eaſtwards. And *Schooten* and others that have gone about by the *Magellan* Streights, have found the limits of S. E. Winds,

Digitized by Google

Winds, much about the ſame Latitude to the Southwards; beſides a farther *Analogy* between the Winds of this Ocean, and the *Æthiopick*, appears in that, upon the Coaſt of *Peru*, they are always much Southerly, like as they are found near the Shores of *Angola*.

Thus far Matter of Fact, wherein if the Information I have receiv'd be not in all parts Accurate, it has not been for want of inquiry from thoſe I conceiv'd beſt able to inſtruct me; and I ſhall take it for a very great Kindneſs if any Maſter of a Ship, or other Perſon, well informed of the Nature of the Winds, in any of the aforementioned parts of the World, ſhall pleaſe to communicate their Obſervations thereupon; ſo that what I have here Collected may be either confirm'd or amended, or by the addition of ſome material Circumſtances enlarg'd. It is not the work of one, nor of few, but of a multitude of Obſervers, to bring together the experience requiſite to compoſe a perfect and compleat Hiſtory of theſe Winds; however I am not much doubtful that I have err'd in, or omitted any of the principal Obſervables, whatever leſſer particulars may have eſcaped my knowledge.

To help the Conception of the Reader in a manner of ſo much difficulty, I believ'd it neceſſary to adjoin a Scheme, *Plate* 2. ſhewing at one view all the various Tracts and Courſes of theſe Winds; whereby 'tis poſſible the thing may be better underſtood, than by any verbal Deſcription whatſoever.

The Limits of theſe ſeveral Tracts are deſigned every where by prickt Lines, as well in the *Atlantick* and *Æthiopick*, where they are the boundaries of the Trade and variable Winds, as

Digitized by Google

as in the *Indian* Ocean, where they also shew the extent of the several *Monsoons*. I could think of no better way to design the course of the Winds on the Map, than by drawing rows of stroaks in the same Line that a Ship would move going always before it; the sharp end of each little stroak pointing out that part of the Horizon, from whence the Wind continually comes; and where there are *Monsoons*, the rows of the stroaks run alternately backwards and forwards, by which means they are thicker there than elsewhere. As to the great South Sea, considering its vast extent, and the little Variety there is in its Winds, and the great *Analogy* between them, and those of the *Atlantick* and *Æthiopick* Oceans; besides that the greatest part thereof is wholly unknown to us; I thought it unnecessary to lengthen the Map therewith.

In the foregoing History are contained several Problems, that merit well the Consideration of our acutest Naturalists, both by reason of the constancy of the Effect, and of the immense Extent thereof; near half the Surface of the Globe being concerned. The chief of these Problems are, 1. Why these Winds are perpetually from the East in the *Atlantick* and *Æthiopick*, as likewise in the *Pacifick* Ocean, between the Latitudes of 30 North and South. 2. Why the said Winds extend no farther with Constancy than to the Latitudes of 30 *deg.* 3. Why there should be a constant South-westerly Wind upon and near the Coast of *Guinea*. 4. Why in the North-part of the *Indian* Ocean the Winds, which for one half year do agree with those of the other two Oceans, should change in the other half Year, and blow from the opposite Points;

Digitized by Google

Points; whilst the Southern part of that Ocean follows the General Rule, and has perpetual Winds about S. E. 5. Why in these General Trade-Winds it should be always true, that to the Northward of the *Æquator* it is inclined to the Northwards of the East; and in South Latitudes, to the Southward thereof. 6. Why in these Seas of *China* there should be so great an Inclination from the East to the North, more than elsewhere; with many more, which it would be much easier to propose than answer.

But lest I should seem to propose to others difficulties which I have not thought worth my own time and Pains, take here the result of an earnest Endeavour after the true reason of the aforesaid *Phænomena*, wherein if I am not able to account for all Particulars, yet 'tis hoped the Thoughts I have spent thereon, will not be judged wholly lost, by the curious in Natural Enquiries.

Wind is most properly defined to be the Stream or Current of the Air, and where such a Current is perpetual and fixt in its course, 'tis necessary that it proceed from a permanent and intermitting Cause. Wherefore some have been inclined to propose the diurnal *Rotation* of the Earth upon its *Axis*, by which, as the *Globe* turns Eastwards, the loose and *fluid* Particles of the Air, being so exceeding light as they be, are left behind, so that in respect of the Earths *Surface* they move Westwards, and become a constant Easterly Wind. This Opinion seems confirmed, for that these Winds are found only near the *Æquinoctial*, in those Parallels of Latitude where the diurnal Motion is swiftest; and I should readily assent to it, if the constant Calms in the *Atlantick* Sea, near the *Æquator*, the

the Weſterly Winds near the Coaſt of *Guiny*; and the *Periodical* Weſterly *Monſoons* under the *Æquator* in the *Indian* Seas, did not declare inſufficiency of that *Hypotheſis*. Beſides the Air being kept to the Earth by the Principle of *Gravity*, would acquire the ſame degree of *Velocity* that the Earths *Surface* moves with, as well in reſpect of the diurnal *Rotation*, as of the Annual about the Sun, which is about thirty times ſwifter.

It remains therefore to ſubſtitute ſome other cauſe, capable of producing a like conſtant effect, not liable to the ſame Objections, but agreable to the known Properties of the Elements of Air and Water, and the Laws of the Motion of fluid Bodies. Such an one is, I conceive, the Action of the Sun Beams upon the Air and Water, as he paſſes every day over the Oceans, conſidered together with the Nature of the Soil, and Situation of the adjoining Continents: I ſay therefore, firſt, that according to the Laws of *Staticks*, the Air which is leſs rarified or expanded by heat, and conſequently more ponderous, muſt have a Motion towards thoſe parts thereof, which are more rarified, and leſs ponderous, to bring it to an *Æquilibrium*; and ſecondly, that the Preſence of the Sun continually ſhifting to the Weſtwards, that part towards which the Air tends, by reaſon of the Rarifaction made by his greateſt *Meridian* Heat, is with him carried Weſtward, and conſequently the tendency of the whole Body of the lower Air is that way.

Thus a general Eaſterly Wind is formed, which being impreſſed upon all the Air of a vaſt Ocean, the Parts impel one the other, and ſo keep moving till the next return of the Sun, whereby

Digitized by Google

whereby ſo much of the Motion as was loſt, is again reſtored, and thus the Weſterly Wind is made perpetual.

From the ſame Principle it follows, that this Eaſterly Wind ſhould on the North-ſide of the *Æquator*, be to the Northwards of the Eaſt, and in South Latitudes to the Southwards thereof; for near the *Line*, the Air is much more rarified, than at a greater diſtance from it; becauſe of the Sun twice in a Year Vertical, and at no time diſtant above 23 deg. and a half; at which diſtance the Heat, being as the Sine of the Angle of Incidence, is but little ſhort of that of the perpendicular Ray. Whereas under the Tropicks, though the Sun ſtay long Vertical, yet he is as long 47 deg. off; which is a kind of Winter, wherein the Air ſo cools, as that the Summer-heat cannot warm it to the ſame degree with that under the Æquator. Wherefore the Air to the Northwards and Southwards, being leſs rarified than that in the middle, it follows, that from both ſides it ought to tend towards the Æquator: This Motion compounded with the former Eaſterly Wind anſwers all the *Phænomena* of the general Trade-winds; which, if the whole Surface of the Globe were Sea, would undoubtedly blow all round the World, as they are found to do in the *Atlantick* and *Æthiopick* Oceans.

But ſeeing that ſo great Continents do interpoſe and break the continuity of the Oceans, regard muſt be had to the Nature of the Soil, and the Poſition of the high Mountains, which I ſuppoſe the two principal Cauſes of the ſeveral Variations of the Winds, from the former general Rule: For if a Country lying near the Sun, prove to be flat, ſandy, low Land, ſuch

as

Digitized by Google

as the Deserts of *Lybia* are usually reported to be, the Heat occasioned by the Reflection of the Suns Beams, and the retention thereof in the Sand, is incredible to those that have not felt it; whereby the Air being exceedingly rarified, it is necessary that the cooler and more dense Air should run thitherwards to restore the *Æquilibrium*: This I take to be the cause, why near the Coast of *Guinea* the Wind always sets in upon the Land, blowing Westerly instead of Easterly, there being sufficient reason to believe, that the Inland Parts of *Africa* are prodigiously hot, since the Northern Borders thereof were so intemperate, as to give the Ancients cause to conclude, that all beyond the *Tropick* was made inhabitable by excess of Heat: From the same cause it happens, that there are so constant Calms in that part of the Ocean, called the *Raines*, (described in the 7th Remark on the *Atlantick* Sea) for this Tract being placed in the middle, between the Westerly Winds blowing on the Coast *Guinea*, and the Easterly Trade-winds, blowing to the Westwards thereof, the tendency of the Air here, is indifferent to either, and so stands in *Æquilibrio* between both; and the weight of the incumbent Atmosphere being diminished by the continual contrary Winds blowing from hence, is the reason that the Air here holds not the copious Vapour it receives, but lets it fall into frequent Rains.

But as to the cool and dense Air, by reason of its greater Gravity, presses upon the hot and rarified, 'tis demonstrative that this latter must ascend in a continued stream as fast it rarifies; and that being ascended, it must disperse it self to preserve the *Æquilibrium*; that is, by a

Digitized by Google

contrary Current, the upper Air must move from those Parts where the greatest Heat is: So by a kind of Circulation, the North-East Trade Wind below, will be attended with a South-Westerly above, and the South Easterly with with a North-West Wind above; that this is more than a bare conjecture, the almost instantaneous change of the Wind to the opposite Point, which is frequently found in passing the limits of the Trade-winds, seems to assure us; but that which above all confirms this *Hypothesis* is the *Phænomenon* of the *Monsoons*, by this means most easily solved, and without it hardly explicable.

Supposing therefore such a Circulation as above, 'tis to be considered that to the Northward of the *Indian* Ocean there is every where Land within the usual limit of the Latitude of 30. *viz. Arabia, Persia, India, &c.* which for the same reason as the *Mediterranean* Parts of *Africa*, are subject to unsufferable Heats when the Sun is to the North, passing nearly Vertical; but yet are temperate enough when the Sun is removed towards the other *Tropick*; because of a ridge of Mountains at some distance within the Land, said to be frequently in Winter covered with Snow, over which the Air, as it passes, must needs be much chilled. Hence it comes to pass that the Air coming according to the general Rule, out of the *N. E.* in the *Indian* Seas, is sometimes hotter, sometimes colder, than that which by this Circulation is returned out of the *S. W.* and by consequence, sometimes the under Current or Wind is from the N. E. sometimes from the S. W.

That

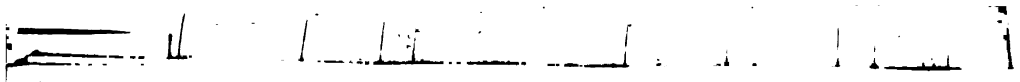
Digitized by Google

That this has no other Cauſe, is clear from the times wherein theſe Winds ſet in, *viz.* in *April*, when the Sun begins to warm thoſe Countries to the North, the S. W. *Monſoon* begins, and blows during the Heats till *October*; when the Sun being retir'd, and all things growing cooler Northward, and the Heat increaſing to the South, the North-Eaſt Winds enter and blow all the Winter till *April* again. And it is undoubtedly from the ſame Principle that to the Southwards of the Æquator, in part of the *Indian* Ocean, the North-Weſt Winds ſucceed the South-Eaſt, when the Sun draws near the *Tropick* of *Capricorn*; but I muſt confeſs, that in this latter occurs a difficulty, not well to be accounted for, which is, why this Change of the *Monſoons* ſhould be any more in this Ocean, than in the ſame Latitudes in the *Æthiopick*, where there is nothing more certain than a S. E. Wind all the Year.

'Tis likewiſe very hard to conceive why the limits of the Trade-Wind ſhould be fixt, about the thirtieth Degree of Latitude all round the Globe; and that they ſhould ſo ſeldom tranſgreſs or fall ſhort of thoſe bounds; as alſo that in the *Indian* Sea, only the Northern Part ſhould be ſubject to the changeable *Monſoons*, and in the Southern there be a conſtant S. E.

Theſe are Particulars that merit to be conſider'd more at large, and furniſh a ſufficient Subject for a juſt Volume, which will be a very commendable Task for ſuch, who being uſed to Philoſophick Contemplation, ſhall have leaſure to apply their ſerious Thoughts about it.

Digitized by Google



Digitized by Google

Digitized by Google

A Discourse of the Rule of the Decrease of the height of the Mercury in the Barometer, according as Places are elevated above the Surface of the Earth; with an Attempt to discover the true Reason of the Rising and Falling of the Mercury, upon Change of Weather. By Edm. Halley.

THE Elastick Property of the Air has been long since made out, by Experiments before the Royal Society and elsewhere; and the Resistance of its Spring is found to be nearly equal to the Weight or Force that compresses it; as also, that the Spaces the same Air occupies, under differing Pressures, are reciprocally as those Pressures: It has been shown likewise by undoubted Experiment, that the specifick Gravity of the Air, near the Earth's Surface to that of Water, was once as 1 to 840; again as 1 to 852; and a third time, in a very large Vessel holding 10 Gallons, as 1 to 860; all which, considering the difficulty of the Experiment, agree well enough, the Mercury standing at all those times about 29 Inches $\frac{1}{4}$: But by reason 'twas Summer-weather, and consequently,

Digitized by Google

quently the Air rarified, when all these were tried, we may without sensible Error say in round numbers, that the Barometer standing at 30 Inches, and in a mean State of Heat and Cold, the specifick Gravity of the Air to Water, is as 1 to 800. By the the like Trials the Weight of Mercury to Water, is as 13½ to 1, or very near it; so that the weight of Mercury to Air, is as 10800 to 1; and a Cylinder of Air of 10800 Inches or 900 Feet, is equal to an Inch of Mercury; and were the Air of an equal density like Water, the whole Atmosphere would be no more than 15, 1 miles high, and in the Ascent of every 900 Feet the Barometer would sink an Inch. But the Expansion of the Air increasing in the same proportion as the incumbent weight of the Atmosphere decreases; that is, as the Mercury in the Barometer sinks, the upper Parts of the *Air* are much more rarified than the lower, and each Space answering to an Inch of Quicksilver grows greater and greater; so that the Atmosphere must be extended to a much greater height. Now, upon these Principles, to determine the height of the *Mercury* at any assigned height in the *Air*; and *e contra*, having the height of the *Mercury* given, to find the height of the Place where the *Barometer* stands, are Problems not more difficult than curious; and which I thus resolve.

The Expansions of the *Air* being reciprocally as the heights of the *Mercury*, it is evident, that by the help of the Curve of the *Hyperbola* and its *Asymptotes*, the said Expansions may be expounded to any given height of the *Mercury*: For by the 65th *Prop. lib.* 2. *Conic. Mydorgii*, the Rectangles, *ABCE*, *AKGE*, *ALDE*, *&c.* (in *Plate* 1. *Fig.* 4.) are always equal, and consequently the

the ſides, *C B*, *G K*, *L D*, &c. are reciprocally as the ſides *A B*, *A K*, *A L*, &c. If then the Lines *A B*, *A K*, *A L*, be ſuppoſed equal to the heights of the *Mercury*, or the preſſures of the Atmoſphere, the Lines *C B*, *K G*, *L D*, anſwering thereto, will be as the Expanſions of the *Air* under thoſe Preſſures, or the bulks that the ſame quantity of *Air* will occupy; which Expanſions being taken infinitely many, and infinitely little, (according to the Method of Indiviſibles) their Summ will give the Spaces of Air between the ſeveral heights of the *Barometer*; that is to ſay, the Summ of all the Lines between *C B* and *K G*, or the *Area C B K G*, will be proportioned to the diſtance or ſpace intercepted between the Levels of two Places in the Air, where the *Mercury* would ſtand at the heights repreſented by the Lines *A B*, *A K*; ſo then the Spaces of Air anſwering to equal Parts of *Mercury* in the *Barometer*, are as the *Area's C B K G*, *G K L D*, *D L F M*, &c. Theſe *Area's* again are, by the Demonſtration of *Gregory* of St. *Vincent*, proportionate to the *Logarithms* of the Numbers expreſſing the *Rationes* of *A K* to *A B*, of *A L* to *A K*, of *A M* to *A L*, &c. So then by the common Table of *Logarithms*, the height of any Place in the *Atmoſphere*, having any aſſigned height of the *Mercury* may moſt eaſily be found: For the Line *C B* in the *Hyperbola*, whereof the *Area's* deſign the *Tabular Logarithms*, being 0, 0144765; 'twill be, as 0, 0144765, to the difference of the *Logarithms* of 30, and any other leſſer Number, for 900 Feet or the Space anſwering to an Inch of *Mercury*, if the Air were equally preſt with 30 Inches of *Mercury*, and every where alike, to the height of the *Barometer* in the *Air*, where it

Digitized by Google

will stand at that lesser number of Inches: And by the Converse of this Proportion may the height of the *Mercury* be found, having the Altitude of the Place given. From these Rules I deriv'd the following Tables.

A Table shewing the Altitude, to given heights of the Mercury.

Inch.	Feet.
30	0
29	915
28	1862
27	2844
26	3863
25	4922
20	10947
15	18715
10	29662
5	48378
1	91831
0. 5	110547
0 25	129262
0. 1	29 mil. or 154000
0. 01	41 mil. or 216169
0. 001	53 mil. 278338

A Table shewing the heights of the Mercury, *at given Altitudes.*

Feet	Inch
0	30 00
1000	28 91
2000	27 86
3000	26 85
4000	25 87
5000 feet	24 93
1 mile	24 67
2	20 29
3	16 68
4	13 72
5	11 28
10	4 24
15	1 60
20	0 95
25	0 23
30	0 08
40	0 012

Upon

UPON theſe Suppoſitions it appears, that at the height of 41 Miles the *Air* is ſo rarified, as to take up 3000 times the Space it occupies here, and at 53 Miles high it would be expanded above 30000 times; but it's probable that the utmoſt Power of its Spring cannot exert it ſelf, to ſo great an Extenſion, and that no part of the *Atmoſphere* reaches above 45 Miles from the Surface of the Earth.

This ſeems confirmed from the Obſervations of the *Crepuſculum*, which is obſerv'd commonly to begin and end when the Summ is about 18 degrees below the Horizon; for ſuppoſing the *Air* to reflect light from its moſt rarified Parts, and that as long as the Sun illuminates any of its *Atoms*, they are viſible to an Eye not intercepted by the Curvity of the Earth, it will follow from *Fig.* 5. *Plate* 1. that the proportion of the height of the whole *Air*, to the Semi-diameter of the Earth, is much about, as 1 to 90, or as the exceſs of the *Secant* of about 8½ degrees to the *Radius*. For if *E* be the Eye of the Obſerver, *S* a Place where the Sun ſets at the end of Twilight in *E*, and the Arch *ECS*, or *TCA* be found 18 degrees, the exceſs of the *Secant* of half thereof *ECH*, would be the height of the *Air*, *viz.* *GH*: But the Beam of the Sun *ASH*, and the Viſual Ray *EH*, do each of them ſuffer a Refraction of about 32 or 33 Minutes, whereby being bent inwards from *H* towards *G*, the height of the *Air* need not be ſo great as if they went ſtreight; and having from the Angle *ECS* taken the double Refraction of the *Horizontal Ray*, the half of the Remainder will be 8½ degrees *Circiter*, whoſe *Secant* being 10 111, it follows that as 10000

Digitized by Google

to 111, so the Semi-diameter of the Earth supposed 4000 Miles, to 44, 4 Miles; which will be the height of the whole *Air*, if the Places *E*, *S*, whose visible Portions of the *Atmosphere* *E R Z H*, and *S H K B* just touch one the other, be 18 degrees asunder.

At this height the *Air* is expanded into above 3000 times the space it occupies here, and we have seen the Experience of condensing it into the 60th part of the same Space; so that it should seem, that the Air is a Substance capable of being compressed into the 180000th part of the Space it would naturally take up, when free from pressure. Now what Texture or Composition of Parts shall be capable of this great Expansion and Contraction, seems a very hard Question; and which, I suppose, is scarce sufficiently accounted for, by comparing it to Wool, Cotton, and the like springy Bodies.

Hitherto I have only consider'd the *Air* and *Atmosphere*, as one unalter'd Body, as having constantly at the Earth's Surface the 800th part of the weight of Water, and being capable of Rarefaction and Condensation *in infinitum*; neither of which *Hypotheses* are rigidly true: For here in *England* it's notoriously known, that the weight of the whole *Atmosphere* is various, being counterpoised sometimes by $28\frac{1}{2}$ Inches of *Mercury*, and at other times by no less than $30\frac{1}{2}$; so that the under parts being pressed by about a 15th part, less weight, the *Specifick* Gravity of the *Air* upon that score will sometimes be a 15th part lighter than another; besides Heat and Cold does very considerably dilate and contract the Air, and consequently alter its Gravity; to which add the mixture of *Effluvia*, or steams arising from almost all Bodies,

Digitized by Google

dies, which aſſimulating into the Form of Air are kept ſuſpended therein, as Salts diſſolv'd in Liquors, or Mettles in corroding *Menſtrua*; which Bodies being all of them very much heavier than *Air*, their Particles by their Admixture muſt needs encreaſe the weight of that *Air* they lie incorporated withal, after the ſame manner as melted Salts do augment the ſpecifick Gravity of Water. The other Conſideration is, that the Rarefaction and Condenſation of the *Air* is not preciſely according to the proportion here laid down; for the Experiment very nearly agrees thereto, as may be ſeen in the 58th Chapter of *Mr. Hook's Micrography*; yet are the Condenſations not poſſible beyond certain degrees: For being compreſſed into an 800th part of the Space it takes up here, its conſiſtence would be equally denſe with that of Water; which yields not to any force whatſoever, as hath been found by ſeveral Experiments tried here, and at *Florence*, by the *Academia del Cimento*. Nor can the Rarefaction proceed *in infinitum*; for ſuppoſing the Spring whereby it dilates it ſelf, occaſion'd by what Texture of Parts you pleaſe, yet muſt there be a determinate Magnitude of the natural State of each Particle, as we ſee it is in Wool and the like, whoſe Bodies being compreſſable into a very ſmall Space, have yet a determinate bulk which they cannot exceed, when free'd from all manner of Preſſure.

Theſe Objections being true, do diſturb the Geometrical Accuracy of theſe Concluſions, drawn from the ſpecifick Gravity of the *Air* obſerv'd at any time; but the Method here ſhewn will compute by a like Calculation, the heights of the *Quick-ſilver*, and the Rarefactions

Digitized by Google

of the *Air* from any assigned height of the *Barometer* at the Earth's Surface, and any specifick Gravity given. As to the Condensation and Rarefaction by Heat and Cold, and the various mixture of Aqueous and other Vapours, these two Objections seem generally to compensate each other; for when the Air is rarified by Heat, they are raised most copiously; so that tho' the *Air* properly so called, be expanded, and consequently lighter, yet the *Interstices* thereof being crouded full of Vapours of much heavier Matters, bulk for bulk, the weight of the *Compositum* may continue much the same; at least a most curious Experiment made by the Ingenious Mr. *John Caswell*, of *Oxford*, upon the top of *Snowdon* Hill, in *Caernarvanshire*, seems to prove, that the first Inches of *Mercury* have their Portions of *Air* near enough to what I now determine: For the height of the Hill being 1240 Yards, or very near it, he found the *Mercury* to have subsided to 25, 6 Inches or 4 Inches below the mean Altitude thereof at the Level of the Sea, (which is a greater difference than has been found in any of our former Experiments,) and the Space answering to 4 Inches, by my Calculation, should be 1288 Yards; and it agrees as well with the Observations in the Appendix to Mr. *Pascall*'s Book, *del' Equilibre des Liqueurs*, made on the high Hill in *Auvergne*, call'd *le puy de Domme*. So that the Rarefaction and Vapours seem not to have altered considerably, the Gravity of the under Parts of the *Air*; and much above the height where these Experiments were made, do few Vapours ascend, and the Cold is such that the Snow lies continually, so that for the more elevated Parts of the Sphere of *Air*, there is much less Reason to doubt. But

Digitized by Google

But now we have had occasion to mention the difference there is between the height of the *Mercury* at one time, from the height thereof at another, it may not be unacceptable to offer at some Reasons for the said difference; which, at least to my self, seem to have some appearance of Truth. *First*, then it's undoubtedly demonstrable, that the height of the Cylinder of *Mercury* is equal to the weight of the whole incumbent *Air*, and consequently that that whole is sometimes a fifteenth more than at other times; which cannot otherwise be, but by the access of new Matter when 'tis heavy, and its diminution when 'tis light; that *Hypothesis* therefore that shews how the *Air* shall be encreased or diminished, in any particular place, will give a Reason for the greater and lesser height of the *Mercury* in the *Baroscope*: But to direct us in the choice of the several Causes, which may be assigned for the Increase and Decrease of the *Air*, 'twill not be unnecessary to enumerate some of the principal Observations made upon the *Barometer*, most whereof are sufficiently known already to all those that are curious in these Matters.

The *First* is, that in calm Weather when the *Air* is inclined to Rain, the *Mercury* is commonly low.

2. That in serene good settled Weather the *Mercury* is generally high.

3. That upon very great Winds, tho' they be not accompanied with Rain, the *Mercury* sinks lowest of all, with relation to the Point of the Compass the Wind blows upon.

4. That

Digitized by Google

4. That *ceteris paribus* the greatest heights of the *Mercury* are found upon Easterly and North-Easterly Winds.

5. That in calm frosty Weather the *Mercury* generally stands high.

6. That after very great Storms of Wind, when the *Quick silver* has been low, it generally rises again very fast.

7. That the more Northerly places have greater alterations of the *Baroscope* than the more Southerly.

8. That within the *Tropicks* and near them, those Accounts I have had from others, and my own Observation at St. *Helena* make very little or no Variation of the height of the *Mercury* in all weathers. Now that Theory that can well account for all these appearances, will, in all probability, approach nearer the true cause of the *Barometers* Variations, than any thing hitherto afforded; and such an one I am bound to believe, is that which I here lay down with submission to better Judgments.

I conceive that the principal Cause of the rise and fall of the *Mercury*, is from the variable Winds, which are found in the *Temperate Zones*, and whose great unconstancy here in *England* is most notorious. I shall not at present inquire into the cause of its uncertainty, but the Matter of Fact being most undoubted, the Legitimate Consequences thereof must be allow'd me, let it proceed from what it will.

Digitized by Google

A ſecond Cauſe is the uncertain Exhalation and Præcipitation of the Vapours lodging in the Air, whereby it comes to be at one time much more crowded than at another, and conſequently heavier; but this latter in a great meaſure depends upon the former. Now from theſe Principles I ſhall endeavour to explicate the ſeveral *Phænomena* of the *Barometer*, taking them in the ſame order I laid them down.

1. *Why in Calm Weather the* Air *being inclin'd to Rain, the* Mercury *is commonly low?* I Anſwer, That the *Mercury*'s being low, inclines it to Rain; for the Air being light, the Vapours are no longer ſupported thereby, being become ſpecifically heavier than the Medium wherein they floated; ſo that they deſcend towards the Earth, and in their fall meeting with other aqueous Particles, they incorporate together, and form little drops of Rain; but the *Mercury*'s being at one time lower than another, is the effect of two contrary Winds blowing from the place whence the *Barometer* ſtands; whereby the *Air* of that place is carried both ways from it, and conſequently the imumbent Cylinder of *Air* is diminiſh'd, and accordingly the *Mercury* ſinks; as for inſtance, if in the *German Ocean* it ſhould blow a Gale of Weſterly Wind, and at the ſame time an Eaſterly Wind in the *Iriſh-Sea*; or if in *France* it ſhould blow a Southerly Wind, and in *Scotland* a Northern; it muſt be granted me, that That part of the *Atmoſphere* impendent over *England*, would thereby be exhauſted and attenuated, and the *Mercury* would ſubſide, and the Vapours which before floated in thoſe parts of the *Air* of equal

Gravity

Digitized by Google

Gravity with themselves, would sink to the Earth.

2. *Why in serene good settled weather the* Mercury *is generally high.* To this I Answer, That the greater height of the *Barometer*, is occasion'd by two contrary Winds blowing *towards* the place of Observation, whereby the *Air* of other places is brought thither and accumulated; so that the incumbent Cylinder of Air being encreased both in height and weight, the *Mercury* press'd thereby, must needs rise and stand high, as long as the Winds continue so to blow; and then the Air being specifically heavier, the Vapours are better kept suspended, so that they have no inclination to Præcipitate and fall down in Drops, which is the reason of the serene good Weather, which attends the greater heights of the *Mercury*.

3. *Why upon very great Winds or Storms, though accompanied with no Rain, the* Mercury *sinks lowest of all, with relation to the Point of the Compass upon which the Wind blows.* This is caus'd by the very rapid Motion of the *Air* in these Storms; for the Tract or Region of the Earths Surface, wherein these Winds rage, not extending all round the Globe, that stagnant *Air* which is left behind, as likewise that on the sides, cannot come in so fast as to supply the Evacuation made by so swift a Current; so that the Air must necessarily be attenuated, when and where the said Winds continue to blow, and that more or less according to their violence; add to which, that the *Horizontal* Motion of the *Air* being so quick as it is, may in all probability take off some part of the perpendicular pressure

Digitized by Google

pressure thereof; and the great agitation of its Particles, is the Reason why the Vapours are dissipated and do not condense into Drops, so as to form Rain, otherwise the natural Consequence of the *Airs* Rarefaction.

4. *Why* cæteris paribus *the* Mercury *stands highest upon an Easterly or North-Easterly Wind.* This happens because that the great *Atlantick Ocean* on this side the thirty fifth Degree of North Latitude, the Westerly and South-Westerly Winds blow almost always *Trade*; so that whenever here the Wind comes up at East and North-East, 'tis sure to be checked by a contrary Gale, as soon as it reaches the *Ocean*; wherefore, according to what is made out in our second Remark, the *Air* must needs be heaped over this Island; and consequently the *Mercury* must stand high, as often as these Winds blow. This holds true in this Country, but is not a general Rule for others, where the Winds are under different Circumstances; and I have sometimes seen the *Mercury* here as low as twenty nine Inches, upon an Easterly Wind, but then it blows exceeding hard, and so comes to be accounted for by what was observ'd upon the third Remark.

5. *Why in calm Weather the* Mercury *generally stands high.* The cause hereof is, as I conceive, that it seldom freezes but when the Winds come out of the Northern and North-Eastern Quarters, or at least unless those Winds blow at no great distance of; for the Northern Parts of *Germany*, *Denmark*, *Sweeden*, *Norway*, and all that Tract from whence North-Eastern Winds come, are subject to almost continual

Digitized by Google

nual Frost all the Winter; and thereby the lower Air is very much condens'd, and in that State is brought hitherwards by these Winds, and being accumulated by the opposition of the Westerly Wind blowing in the Ocean, the *Mercury* must needs be prest to a more than ordinary height, and as a concurring Cause, the shrinking of the lower parts of the *Air* into less room by cold, must needs cause a descent of the upper parts of the Atmosphere to reduce the Cavity made by this contraction to an *Equilibrium*.

6. *Why after very great Storms of Wind, when the Mercury has been very low, it generally rises again very fast.* This I have frequently observ'd, and once found it risen an Inch and a half in less than six Hours, after a long continu'd Storm at South-West Wind. This seems to be occasion'd by the suddain Accession of new *Air* to supply the great Evacuation which such continu'd Storms make thereof, in those places whence they happen (as in the third Remark) and by the Recoile of the Air, after the force ceases that impell'd it; and the Reason why the *Mercury* rises so fast, is because the Air being very much rarify'd beyond its mean density, the Neighbouring *Air* runs in the more swiftly to bring it to an *Equilibrium*, as we see Water runs the faster for having a great declivity.

7. *Why in many Northerly places the variations of the Barnscoop are greater than in the Southerly.* The truth of the Matter of Fact is proved from Observations made at *Clermont* and *Paris* compar'd with others made at *Stockholm*, as may be seen in the Appendix to Mr. Perry's Book before

Issuit

fore-cited. The Reason I conjecture to be that the more Northerly Parts have usually greater Storms of Wind than the more Southerly, whereby the *Mercury* should sink lower in that extream; and then the Northerly Winds bringing the condens'd and ponderous *Air* from the Neighbourhood of the Pole, and that again being checked by a Southerly Wind, at no great distance, and so heaped must of necessity make the *Mercury* in such case stand higher, in the other extream.

8. And Lastly, *Why near the* Æquinoctial *as at* Barbadoes *and St.* Helena, *there is very little or no Variation of the height of the Barometer.* This Remark, above all others, confirms the Hypothesis of the variable Winds, being the cause of these Variations of the height of the *Mercury*; for in the places above-named, there is always an easie Gale of Wind blowing nearly upon the same Point, *viz.* E, N, E, at *Barbadoes*, and E, S, E, at St. *Helena*; so that there being no contrary Currents of the Air, to exhaust or accumulate it, the Atmosphere continues much in the same State: However upon Hurricanes, the most violent of Storms, the *Mercury* has been observ'd very low, but this is but for once in two or three Years, and it soon recovers its settled state of about 29½ Inches. I doubt not but the same thing is in the East Coast of *Africa*, and in *India*, where the Monsoons or Winds are Trade for half the Year one way, and half the Year another; only its probable, that there may something worth noting happen, about the times of the change or shifting of the Winds, which might be obtain'd

Digitized by Google

tain'd if any Body had the curiosity to keep the *Barometer* at our Factories in *India*.

I doubt not but this Doctrine will find some Opposers, and that one principal Objection will be, that I suppose the *Air* sometimes to move *from* those parts where it is already evacuated below the *Equilibrium*, and sometimes again towards those parts, where it is condens'd and crouded above the mean state, which may be thought contradictory to the Laws of Staticks and the Rules of the *Equilibrium* of Fluids. But those that shall consider how, when once an impetus is given to a Fluid Body, it is capable of mounting above its level, and checking others that have a contrary tendency to descent by their own Gravity, will no longer regard this as a material Obstacle, but will rather conclude, that the great *Analogy* there is between the rising and falling of the Water upon the Flux and Reflux of the Sea, and this of the accumulating and extenuating the Air, is a great Argument for the Truth of this Hypothesis: For as the Sea overagainst the Coast of *Essex*, rises and swells by the meeting of the two contrary Tides of Flood, (whereof the one comes from the S. W. along the Channel of *England*, and the other from the North); and on the contrary sinks below its level upon the retreat of the Water both ways in the Tide of Ebb; so it is very probable that the Air may Ebb and Flow, after the same manner; but by reason of the diversity of Causes, whereby the *Air* may be set in moveing, the times of these *Fluxes* and *Refluxes* thereof, are purely Casual and not reducible to any Rule, as are the Motions of the Sea, depending wholly upon the regular Course of the Moon.

Digitized by Google

Digitized by Google

Digitized by Google

A Letter of Mr. Iſaac Newton, *Profeſſor of the Mathematicks in the Univerſity of* Cambridge; *containing his New Theory about* Light *and* Colours: *Sent by the Author to the Publiſher from* Cambridge, *Febr.* 6. $16\frac{71}{72}$; *in order to be communicated to the* R. Society.

SIR,

TO perform my late promiſe to you, I ſhall without further Ceremony acquaint you, that in the beginning of the Year 1666 (at which time I apply'd my ſelf to the grinding of Optick-glaſſes of other Figures than *Spherical*,) I procur'd me a Triangular Glaſs-Priſm, to try therewith the celebrated *Phænomena* of *Colours*. And in order thereto having darken'd my Chamber, and made a ſmall hole in my Window-ſhuts, to let in a convenient quantity of the Suns Light, I plac'd my Priſme at his entrance, that it might be thereby refracted to the oppoſite Wall. It was at firſt a very pleaſing divertiſement, to view the vivid and intenſe Colours produced thereby; but after a while applying my ſelf to conſider them more circumſpectly, I became ſurpriſed to ſee them in an *oblong* Form; which, according to the received

Digitized by Google

ceiv'd Laws of Refraction, I expected ſhould have been *Circular*.

They were terminated at the ſides with ſtreight Lines, but at the ends, the decay of Light was ſo gradual, that it was difficult to determine juſtly, what was their Figure; yet they ſeem'd *Semicircular*.

Comparing the length of this colour'd *Spectrum* with its breadth, I found it about five times greater; a diſproportion ſo extravagant, that it excited me to a more than ordinary Curioſity of examining, from whence it might proceed. I could ſcarce think, that the various thickneſs of the Glaſs, or the termination with ſhadow or darkneſs, could have any Influence on Light to produce ſuch an effect; yet I thought it not amiſs, firſt to examine thoſe Circumſtances, and ſo try'd, what would happen by tranſmitting Light through parts of the Glaſs of divers thickneſſes, or through holes in the Window of divers bigneſſes, or by ſetting the Priſm without ſo, that the light might paſs through it, and be refracted before it was terminated by the hole: But I found none of thoſe Circumſtances material. The faſhion of the Colours was, in all theſe Caſes, the ſame.

Then I ſuſpected, whether by any unevenneſs in the Glaſs, or other contingent Irregularity, theſe Colours might be thus dilated. And to try this, I took another Priſm like the former, and ſo plac'd it, that the light paſſing through them both, might be refracted contrary ways, and ſo by the latter return'd into that Courſe, from which the former had diverted it. For, by this means, I thought the *regular* effects of the firſt Priſm would be deſtroy'd by the ſecond Priſm, but the *irregular* ones more

Digitized by Google

more augmented by the multiplicity of Refractions. The event was, that the light, which by the first Prism was diffused into an *oblong* Form, was, by the second, reduc'd into an *orbicular* one with as much regularity, as when it did not at all pass through them. So that whatever was the cause of that length, 'twas not any contingent Irregularity.

I then proceeded to examine more critically, what might be effected by the difference of the incidence of Rays coming from divers parts of the Sun; and to that end, measur'd the several Lines and Angles belonging to the Image. Its distance from the Hole or Prism was twenty two Foot; its utmost length $13\frac{1}{4}$ Inches; its breadth $2\frac{1}{8}$; the Diameter of the Hole $\frac{1}{4}$ of an Inch; the Angle, with the Rays, tending towards the middle of the Image, made with those Lines, in which they would have proceeded without Refraction, was 44 Deg. 56′. And the Vertical Angle of the Prism, 63 Deg. 12′. Also the Refractions on both sides the Prisme, that is, of the Incident, and Emergent Rays, were as near, as I could make them, equal, and consequently about 54 Deg. 4′. And the Rays fell perpendicularly upon the Wall. Now subducting the Diameter of the Hole from the length and breadth of the Image, there remains 13 Inches the length, and $2\frac{3}{8}$ the breadth, comprehended by those Rays, which passed through the Center of the said Hole, and consequently the Angle of the Hole, which that breadth subtended, was about 31′, answerable to the Suns Diameter; but the Angle, which its length subtended, was more than five such Diameters, namely two Deg. 49′.

Digitized by Google

Having made theſe Obſervations, I firſt computed from them the refractive Power of that Glaſs, and found it meaſur'd by the *ratio* of the Sines, twenty to thirty one. And then, by that *ratio*, I computed the Refractions of two Rays flowing from oppoſite parts of the Sun's *diſcus*, ſo as to differ 31′ in their obliquity of Incidence, and found, that the emergent Rays ſhould have comprehended an Angle of about 31′, as they did, before they were incident.

But becauſe this computation was founded on the Hypotheſis of the proportionality of the ſines of Incidence and Refraction, which, tho' by my own Experience I could not imagine to be ſo erroneous as to make that Angle but 31′, which in reality was two Deg. 49′; yet my curioſity caus'd me again to take my Priſm. And having plac'd it at my Window, as before, I obſerv'd, that by turning it a little about its *Axis* to and fro, ſo as to vary its obliquity to the light, more than an Angle of four or five Degrees, the Colours were not thereby ſenſibly tranſlated from their place on the Wall, and conſequently by that variation of Incidence, the quantity of Refraction was not ſenſibly varied. By this Experiment therefore, as well as by the former computation, it was evident, that the difference of the Incidence of Rays, flowing from divers parts of the Sun could not make them, after decuſſation, diverge at a ſenſibly greater Angle, than that at which they before converged; which being, at moſt, but about thirty one or thirty two Minutes, there ſtill remain'd ſome other cauſe to be found out, from whence it could be two Deg. 49′.

Then

Digitized by Google

Then I began to suspect, whether the Rays, after their Trajection through the Prism, did not move in curve Lines, and according to their more or less Curvity tend to divers parts of the Wall. And it increas'd my suspicion, when I remember'd that I had often seen a Tennis-Ball, struck with an oblique Racket, describe such a curve Line. For, a Circular as well as a Progressive Motion being communicated to it by that stroak, its parts on that side, where the Motions consPire, must press and beat the contiguous Air more violently than on the other, and there excite a reluctancy and reaction of the Air proportionably greater. And for the same reason, if the Rays of Light should possibly be globular Bodies, and by their oblique Passage out of one Medium into another, acquire a circulating Motion, they ought to feel the greater resistence from the ambient Æther, on that side, where this Motions consPire, and thence be continually bowed to the other. But notwithstanding this plausible ground of suspicion, when I came to examine it, I could observe no such Curvity in them. And besides (which was enough for my purpose) I obserV'd, that the difference 'twixt the length of the Image, and Diameter of the Hole, through which the light was transmitted, was proportionable to their distance.

The gradual removal of these suspicions, at length led me to the *Experimentum Crucis*, which was this; I took two Boards, and plac'd one of them close behind the Prism at the Window, so that the light might pass through a small hole, made in it for the purpose, and fall on the other Board, which I plac'd at about twelve Feet distance, having first made a small

Digitized by Google

hole in it also, for some of that incident Light to pass through. Then I plac'd another Prism behind this second Board, so that the Light, trajected through both the Boards, might pass through that also, and be again refracted before it arrived at the Wall. This done, I took the first Prism in my Hand, and turn'd it to and fro slowly about its *Axis*, so much as to make the several parts of the Image, cast on the second Board, successively pass through the hole in it, that I might observe to what places on the Wall the second Prism would refract them. And I saw by the variation of those places, that the Light, tending to that end of the Image, towards which the Refraction of the first Prism was made, did, in the second Prism, suffer a Refraction considerably greater than the Light tending to the other end. And so the true cause of the length of that Image was detected to be no other, than that *Light* consists of *Rays differently refrangible*, which, without any respect to a difference in their incidence, were, according to their degrees of refrangibility, transmitted towards divers parts of the Wall.

When I understood this I left off my aforesaid Glass Works; for I saw, that the perfection of Telescopes was hitherto limited, not so much for want of Glasses truly figured according to the prescriptions of Optick-Authors (which all Men have hitherto imagin'd), as because that Light itself is a *Heterogeneous mixture of differently refrangible Rays*. So that, were a Glass so exactly figured, so as to collect any one sort of Rays into one Point, it could not collect those also into the same point, which having the same Incidence upon the same Medium are apt to suffer

Digitized by Google

suffer a different Refraction. Nay, I wonder'd, that seeing the difference of Refrangibility was so great, as I found it, Telescopes should arrive to that perfection they are now at. For, measuring the Refractions in one of my Prismes, I found, that, supposing the common Sine of Incidence upon one of its plains, was fourty four Parts, the Sine of Refraction of the utmost Rays on the red end of the Colours, made out of the Glass into the Air, would be sixty eight parts, and the Sine of Refraction of the the utmost Rays on the other end, sixty nine parts; so that the difference is about a twenty fourth or twenty fifth part of the whole Refraction. And consequently, the Object-glass of any Telescope cannot collect all the Rays, which come from one point of an Object, so as to make them convene at its *focus* in less room than in a Circular space, whose Diameter is the fiftieth part of the Diameter of its Aperture; which is an irregularity, some hundreds of times greater, than a circularly figured *Lens*, of so small a section as the Object-glasses of long Telescopes are, would cause by the unfitness of its Figure, were Light *uniform*.

This made me take *Reflections* into consideration, and finding them regular, so that the Angle of Reflection of all sorts of Rays was equal to their Angle of Incidence; I understood, that by their mediation, Optick Instruments might be brought to any degree of Perfection imaginable, provided a *Reflecting* Substance could be found, which would polish as finely as Glass, and *reflect* as much Light as Glass *transmits*, and the art of communicating to it a *Parabolick* Figure be also attain'd. But there seem'd very great difficulties, and I have al-

Digitized by Google

moſt thought them inſuperable, when I further conſider'd, that every irregularity in a reflecting Superficies makes the Rays ſtray five or ſix times more out of their due courſe, than the like irregularities in a refracting one: So that a much greater curioſity would be here requiſite, than in Figuring Glaſſes for Refraction.

Amidſt theſe Thoughts I was forc'd from *Cambridge* by the Intervening Plague, and it was more than two Years before I proceeded further. But then having thought on a tender way of poliſhing, proper for Metal, whereby, as I imagin'd, the Figure alſo would be corrected to the laſt; I began to try, what might be effected in this kind, and by degrees ſo far perfected an Inſtrument (in the eſſential parts of it like that I ſent to *London*,) by which I could diſcern *Jupiters* four Concomitants, and ſhew'd them divers times to two others of my Acquaintance. I could alſo diſcern the Moon-like Phaſe of *Venus*, but not very diſtinctly, nor without ſome niceneſs in diſpoſing the Inſtrument.

From that time I was interrupted till this laſt Autumn, when I made the other. And as that was ſenſibly better than the firſt (eſpecially for Day-Objects,) ſo I doubt not but they will be ſtill brought to a much greater perfection by their endeavours, who, as you inform me, are taking care about it at *London*.

I have ſometimes thought to make a *Microſcope*, which in like manner ſhould have, inſtead of an Object-glaſs, a reflecting piece of Metal. And this I hope they will alſo take into conſideration: For thoſe Inſtruments ſeem as capable of improvement as *Teleſcopes*, and perhaps

Digitized by Google

perhaps more, because but one reflective piece of Metal is requisite in them, as you may perceive in *Plate* 3. *Fig.* 1. where *AB* represenleth the Object Metal, *CD* the Eye-glass, *F* their common Focus, and *O* the other Focus of the Metal, in which the Object is placed.

But to return from this digression, I told you, that Light is not similar, or homogeneal, but consists of *differm* Rays, some of which are more refrangible than others: So that of those, which are alike incident on the same Medium, some shall be more refracted than others, and that not by any virtue of the Glass, or other external Cause, but from a predisposition, which every particular Ray hath to suffer a particular degree of Refraction.

I shall now proceed to acquaint you with another more notable deformity in its Rays, wherein the *Origin of Colours* is unfolded: Concerning which I shall lay down the *Doctrine* first, and then, for its examination, give you an Instance or two of the *Experiments*, as a Specimen of the rest.

The Doctrine you will find comprehended and illustrated in the following Propositions.

1. As the Rays of Light differ in degrees of Refrangibility, so they also differ in their disposition to exhibit this or that particular Colour. Colours are not *Qualifications of Light*, derived from Refractions, or Reflections of natural Bodies (as 'tis generally believed) but *Original* and *connate Properties*, which in divers Rays are divers. Some Rays are disposed to exhibit a red Colour and no other; some a yellow and no other, some a green and no other, and so of the rest. Nor are there only Rays proper and particular to the more eminent Colours,

Digitized by Google

lours, but even to all their intermediate Gradations.

2. To the ſame degree of Refrangibility ever belongs the ſame Colour, and to the ſame Colour ever belongs the ſame degree of Refrangibility. The *leaſt Refrangible* Rays are all diſpoſed to exhibit a *Red* Colour, and contrarily thoſe Rays, which are diſpoſed to exhibit a *Red* Colour, are all the leaſt refrangible: So the *moſt Refrangible* Rays are all diſpoſed to exhibit a deep *Violet Colour*, and contrarily thoſe which are apt to exhibit ſuch a Violet Colour, are all the moſt Refrangible. And ſo to all the intermediate Colours in a continued Series belong intermediate degrees of Refrangibility. And this Analogy 'twixt Colours, and Refrangibility, is very preciſe and ſtrict; the Rays always either exactly agreeing in both, or proportionally diſagreeing in both.

3. The Species of Colour, and degree of Refrangibility proper to any particular ſort of Rays, is not mutable by Refraction, nor by Reflection from natural Bodies, nor by any other cauſe, that I could yet obſerve. When any one ſort of Rays hath been well parted from thoſe of other kinds, it hath afterwards obſtinately retained its Colour, notwithſtanding my utmoſt Endeavours to change it. I have refracted it with Priſmes, and reflected it with Bodies, which in Day-light were of other Colours; I have intercepted it with the coloured Film of Air interceding two compreſſed Plates of Glaſs; tranſmitted it through coloured Mediums, and through Mediums irradiated with other ſorts of Rays, and diverſly terminated it; and yet could never produce any new Colour out

Digitized by Google

out of it. It would by contracting and dilating become more brisk, or faint, and by the loss of many Rays, in some cases very obscure and dark; but I could never see it changed *in specie*.

Yet seeming Transmutations of Colours may be made, where there is any mixture of divers sorts of Rays. For in such Mixtures, the component Colours appear not, but, by their mutual allaying each other, constitute a midling Colour. And therefore, if by Refraction, or any other of the aforesaid Causes, the differm Rays, latent in such a mixture, be separated, there shall emerge Colours different from the colour of the Composition. Which colours are not new generated, but only made apparent by being parted; for if they be again intirely mix'd and blended together, they will again compose that Colour, which they did before separation. And for the same reason, Transmutations made by the convening of divers Colours are not real; for when the differm Rays are again severed, they will exhibit the very same Colours, which they did before they entered the Composition; as you see, *Blue* and *Yellow* Powders, when finely mixed, appear to to the naked Eye *Green*, and yet the Colours of the component Corpuscles are not thereby really transmuted, but only blended. For, when viewed with a good Microscope, they still appear *Blue* and *Yellow* interspersedly.

5. There are therefore two sorts of Colours. The one original and simple, the other compounded of these. The Original or primary Colours are, *Red*, *Yellow*, *Green*, *Blue*, and a *Violet-purple*, together with Orange, Indico, and an indefinite variety of intermediate Gradations.

6. The

Digitized by Google

6. The ſame Colours in *Specie* with theſe primary ones, may be alſo produced by Compoſition: For, a mixture of *Yellow* and *Blue* makes *Green*; of *Red* and *Yellow*, makes *Orange*; of *Orange* and *Yellowiſh green*, makes *Yellow*. And in general, if any two Colours be mixed, which in the Series of thoſe, generated by the Priſme, are not too far diſtant one from another, they by their mutual alloy compound that Colour, which in the ſaid Series appeareth in the midway between them. But thoſe, which are ſituated at too great a diſtance, do not ſo. *Orange* and *Indico* produce not the intermediate Green, nor Scarlet and Green the intermediate Yellow.

7. But the moſt ſurpriſing and wonderful Compoſition was that of *Whiteneſs*. There is no one ſort of Rays which alone can exhibit this. 'Tis ever compounded, and to its Compoſition are requiſite all the aforeſaid primary Colours, mixed in a due proportion. I have often with admiration beheld, that all the Colours of the Priſm being made to converge, and thereby to be again mixed as they were in the light before it was incident upon the Priſm, reproduced light, intirely and perfectly white, and not at all ſenſibly differing from a *direct* Light of the Sun, unleſs when the Glaſſes, I uſed, were not ſufficiently clear; for then they would a little incline it to *their* Colour.

8. Hence therefore it comes to paſs, that *Whiteneſs* is the uſual Colour of *Light*; for, Light is a confuſed aggregate of Rays indued with all ſorts of Colours, as they are promiſcuouſly darted from the various Parts of luminous Bodies. And of ſuch a confuſed aggregate, as I ſaid, is generated Whiteneſs, if there be a due

Digitized by Google

due proportion of the Ingredients; but if any one predominate, the Light must incline to that Colour; as it happens in the blue Flame of Brimstone, the yellow Flame of a Candle, and the various Colours of the fixed Stars.

9. These things considered, the *manner*, how Colours are produced by the Prism, is evident. For, of the Rays, constituting the incident Light, since those which differ in Colour proportionally differ in Refrangibility, *they* by their unequal Refractions must be severed and dispersed into an oblong Form, in an orderly succession from the least refracted Scarlet to the most refracted Violet. And for the same reason it is, that Objects, when looked upon through a Prism, appear coloured. For, the difform Rays, by their unequal Refractions, are made to diverge towards several Parts of the *Retina*, and there express the Images of things coloured, as in the former case they did the Sun's Image upon a Wall. And by this inequality of Refractions, they become not only coloured, but also very confused and indistinct.

10. Why the Colours of the *Rainbow* appear in falling drops of Rain, is also from hence evident. For, those drops, which refract the Rays, disposed to appear purple, in greatest quantity to the Spectators Eye, refract the Rays of other sorts so much less, as to make them pass beside it; and such are the drops on the inside of the *Primary* Bow, and on the outside of the *Secondary* or Exteriour one. So those drops, which refract in greatest plenty the Rays, apt to appear red, toward the Spectator's Eye, refract those of other sorts so much more, as to make them pass beside it; and such are the drops

Digitized by Google

drops on the exteriour part of the *Primary*, and interiour part of the *Secondary* Bow.

11. The odd Phænomena of an infusion of *Lignum Nephriticum*, *Leaf-gold*, *Fragments of coloured Glass*, and some other transparently coloured Bodies, appearing in one Position of one Colour, and of another in another, are on these grounds no longer Riddles. For, those are Substances apt to reflect one sort of Light, and transmit another; as may be seen in a dark room, by illuminating them with similar or uncompounded Light. For, then they appear of that Colour only, with which they are illuminated; but yet in one Position more vivid and luminous than in another, accordingly as they are disposed more or less to reflect or transmit the incident Colour.

12. From hence also is manifest the reason of an unexpected Experiment, which Mr. *Hook* somewhere in his *Micrography* relates to have made with two wedge-like transparent Vessels, fill'd the one with a red, the other with a blue Liquor; namely, that though they were severally transparent enough, yet both together became opake: For, if one transmitted only red, and the other only blue, no Rays could pass through both.

13. I might add more Instances of this Nature; but I shall conclude with this general one, that the Colours of all natural Bodies have no other Origin than this, that they are variously qualified to reflect one sort of Light in greater plenty than another. And this I have experimented in a dark room, by illuminating those Bodies with uncompounded Light of divers Colours. For by that means any body may be made to appear of any Colour. They have there

Digitized by Google

there no appropriate Colour, but ever appear of the Colour of the Light cast upon them; but yet with this difference, that they are most brisk and vivid in the Light of their own day-light-colour. *Minium* appeareth there of any Colour indifferently, with which 'tis illustrated, but yet most luminous in red; and so *Bise* appeareth indifferently of any Colour with which 'tis illustrated, but yet most luminous in blue. And therefore *Minium* reflecteth Rays of any Colour, but most copiously those endued with red; and consequently when illustrated with day-light, that is, with all sorts of Rays promiscuously blended, those qualified with red shall abound most in the reflected Light, and by their prevalence cause it to appear of that Colour. And for the same reason *Bise*, reflecting blue most copiously, shall appear blue by the excess of those Rays in its reflected Light; and the like of other Bodies. And that this is the intire and adequate cause of their Colours, is manifest, because they have no power to change or alter the Colours of any sort of Rays incident apart, but put on all Colours indifferently, with which they are inlightned.

These things being so, it can be no longer disputed, whether there be Colours in the dark, nor whether they be the Qualities of the Objects we see, no nor perhaps, whether Light be a Body. For, since Colours are the *Qualities* of Light, having its Rays for their intire and immediate Subject, how can we think those Rays *Qualities* also, unless one Quality may be the subject of and sustain another; which in effect is to call it *Substance*. We should not know Bodies for Substances, were it not for their sensible Qualities; and the principal of those being now found

Digitized by Google

found due to ſomething elſe, we have as good reaſon to believe that to be a Subſtance alſo.

Beſides, whoever thought any Quality to be a *heterogeneous* aggregate, ſuch as Light is diſcovered to be? But, to determine more abſolutely, what Light is, after what manner refracted, and by what modes or actions it produceth in our Minds the Phantaſms of Colours, is not ſo eaſie. And I ſhall not mingle Conjectures with Certainties.

Reviewing what I have written, I ſee the Diſcourſe it ſelf will lead to divers Experiments ſufficient for its Examination; and therefore I ſhall not trouble you farther, than to deſcribe one of thoſe, which I have already inſinuated.

In a darkened Room, make a hole in the ſhut of a Window, whoſe Diameter may conveniently be about a third part of an Inch, to admit a convenient quantity of the Sun's Light: And there place a clear and colourleſs Priſm, to refract the entring Light towards the farther part of the room; which, as I ſaid, will thereby be diffuſed into an oblong coloured Image. Then place a *Lens* of about three Foot Radius (ſuppoſe a broad Object-glaſs of a three Foot Teleſcope,) at the diſtance of about four or five Foot from thence, through which all thoſe Colours may at once be tranſmitted, and made by its Refraction to convene at a farther diſtance of about ten or twelve Feet. If at that diſtance you intercept this Light with a ſheet of white Paper, you will ſee the Colours converted into whiteneſs again by being mingled. But it is requiſite, that the *Priſm* and *Lens* be placed ſteddy, and that the Paper, on which the Colours are caſt, be moved to and fro; for, by ſuch motion, you will not only find at what diſtance

the

the whiteneſs is moſt perfect, but alſo ſee, how the Colours gradually convene, and vaniſh into whiteneſs; and afterwards, having croſſed one another in that place where they compound Whiteneſs, are again diſſipated and ſevered, and in an inverted order retain the ſame Colours, which they had before they entered the Compoſition. You may alſo ſee, that, if any of the Colours at the *Lens* be intercepted, the Whiteneſs will be changed into the other Colours. And therefore, that the Compoſition of whiteneſs be perfect, care muſt be taken that none of the Colours fall beſides the *Lens*.

In the annexed Deſign, *Tab.* 3. *Fig.* 2. of this Experiment, *A B C* expreſſeth the Priſm ſet endwiſe to ſight, cloſe by the hole *F* of the Window *E G*. Its vertical Angle *A B C* may conveniently be about 60 degrees: *M N* deſigneth the *Lens*. Its breadth $2\frac{1}{2}$ or 3 Inches. *S F* one of the ſtreight Lines, in which difform Rays may be conceived to flow ſucceſſively from the Sun. *F P*, and *F R* two of thoſe Rays unequally refracted, which the *Lens* makes to converge towards *Q*, and after decuſſation to diverge again. And *H I* the Paper, at divers diſtances, on which the Colours are projected which in *Q* conſtitute *Whiteneſs*, but are *Red* and *Yellow* in *R*, *r*, and *ρ*, and *Blue* and *Purple* in *P*, *p*, and *π*.

If you proceed further to try the impoſſibility of changing any uncompounded Colour (which I have aſſerted in the third and thirteenth Propoſitions,) 'tis requiſite that the Room may be very dark, leſt any ſcattering light, mixing with the Colour, diſturb and allay it, and render it compound, contrary to the deſign of the Experiment. 'Tis alſo requiſite, that there be

Digitized by Google

a perfecter ſeparation of the Colours, than, after the manner above deſcribed, can be made by the Refraction of one ſingle Priſm; and how to make ſuch farther ſeparations, will ſcarce be difficult to them, that conſider the diſcovered Laws of Refractions. But if trial ſhall be made with Colours not througly ſeparated, there muſt be allowed changes proportionable to the mixture. Thus if compound Yellow light fall upon blue *Biſe*, the Biſe will not appear perfectly yellow, but rather green, becauſe there are in the yellow mixture many Rays indued with green, and green being leſs remote from the uſual blue Colour of Biſe than yellow, is the more copiouſly reflected by it.

In like manner, if any one of the Priſmatick Colours, ſuppoſe red, be intercepted, on deſign to try the aſſerted impoſſibility of reproducing that Colour out of the others which are pretermitted; 'tis neceſſary, either that the Colours be very well parted before the red be intercepted; or that, together with the red, the neighbouring Colours, into which any red is ſecretly diſperſed, (that is, the yellow, and perhaps green too) be intercepted; or elſe, that allowance be made for the emerging of ſo much red out of the yellow green, as may poſſibly have been diffuſed, and ſcatteringly blended in thoſe Colours. And if theſe things be obſerved, the new Production of red, or any intercepted Colour will be found Impoſſible.

This, I conceive, is enough for an Introduction to Experiments of this kind; which if any of the *Royal Society* ſhall be ſo curious as to proſecute, I ſhould be very glad to be informed with what ſucceſs: That, if any thing ſeem to be defective, or to thwart this Relation, I may have

have an opportunity of giving farther Direction about it, or of acknowledging my Errors, if I have committed any.

Since the Publication of this Theory, some Misunderstandings happening between a French *Philosopher at* Paris *and Mr.* Newton, *he has endeavour'd to explain himself a little further in these Things according to the following Method.*

DEFINITIONS.

1. I call that Light Homogeneal, Similar, or Uniform, whose Rays are equally refrangible.

2. And that Heterogeneal, whose Rays are unequally refrangible.

Note, There are but three Affections of Light in which I have observed its Rays to differ; *viz.* Refrangibility, Reflexibility, and Colour; and those Rays which agree in Refrangibility agree also in the other two, and therefore may well be defined Homogeneal; especially since Men usually call those things Homogeneal, which are so in all Qualities that come under their Knowledge, 'though in other Qualities that their Knowledge extends not to, there may possibly by some Heterogeneity.

3. Those Colours I call Simple or Homogeneal, which are exhibited by Homogeneal Light.

4. And those Compound or Heterogeneal, which are exhibited by Heterogeneal Light.

5. Different Colours, I call, not only the more eminent Species Red, Yellow, Green, Blue, Purple, but all other the minutest Gradations;

Digitized by Google

much after the ſame manner, that not only the more eminent Degrees in Muſick, but all the leaſt Gradations, are eſteemed different Sounds.

PROPOSITIONS.

1. The Sun's Light conſiſts of Rays differing by indefinite Degrees of Refrangibility.

2. Rays which differ in Refrangibility, when parted from one another, do proportionally differ in the Colours which they exhibit. Theſe Two Propoſitions are Matter of Fact.

3. There are as many Simple or Homogeneal Colours, as Degrees of Refrangibility. For to every Degree of Refrangibility belongs a different Colour, by *Prop.* 2. and that Colour is ſimple, by *Def.* 1, and 3.

4. Whiteneſs, in all reſpects like that of the Sun's immediate Light, and of all the uſual Objects of our Senſes, cannot be compounded of two ſimple Colours alone. For ſuch a Compoſition muſt be made by Rays that have only two Degrees of Refrangibility, by *Def.* 1, and 3. and therefore it cannot be like that of the Sun's Light, by *Prop.* 1. nor, for the ſame Reaſon, like that of ordinary white Objects.

5. Whiteneſs, in all reſpects, like that of the Sun's immediate Light, cannot be compounded of ſimple Colours without an indefinite Variety of them. For to ſuch a Compoſition, there are requiſite Rays endued with all the indefinite Degrees of Refrangibility, by *Prop.* 1. And thoſe infer as many ſimple Colours, by *Def.* 1, and 3. and *Prop.* 2, and 3.

To make theſe a little plainer, I have added alſo the Propoſitions that follow.

6. The

Digitized by Google

6. The Rays of Light do not act on one another, in paſſing thro' the ſame Medium.

7. The Rays of Light ſuffer not any change of their Qualities from Refraction.

8. Nor afterwards from the adjacent quiet *Medium*: Theſe two Propoſitions are manifeſt *de Facto* in Homogeneal Light, whoſe Colour and Refrangibility is not at all changeable, either by Refraction, or by the contermination of a quiet *Medium*. And as for Heterogeneal Light, it is but an Aggregate of ſeveral ſorts of Homogeneal Light, no one ſort of which ſuffers any more alteration than if it were alone; becauſe the Rays act not on one another, by *Prop.* 6. and therefore the Aggregate can ſuffer none. Theſe two Propoſitions alſo might be further proved apart, by Experiments too long to be here deſcribed.

9. There can no Homogeneal Colours be educed out of Light by Refraction, which were not commixt in it before: Becauſe by *Prop.* 7, and 8. Refraction changeth not the Qualities of the Rays, but only ſeparates thoſe which have divers Qualities, by means of their different Refrangibility.

10. The Sun's Light is an Aggregate of an indefinite Variety of Homogeneal Colours, by *Prop*, 1, 3, and 9. And hence it is, that I call Homogeneal Colours alſo Primitive or Original. And thus much concerning Colours.

For a further Illuſtration of this Doctrin, Mr. Newton, *in his Book of Opticks lately publiſhed, has by undeniable Experiments explained moſt of the Principal Phænomena of Light and Colours: To which we refer the Reader.*

Digitized by Google

A Demonstration concerning the Motion of Light, communicated from Paris.

PHilosophers have been labouring for many Years to decide by some Experiment, whether the Action of Light be conveyed in an instant to distant Places, or whether it requireth time. M. *Romer*, of the *Royal Academy* of Sciences, hath devised a way taken from the Observations of the first Satellit of *Jupiter*, by which he demonstrates, that for the distance of about 3000 Leagues, such as is very near the bigness of the Diameter of the Earth, Light needs not one Second of Time.

Let (in *Fig.* 3. *Plate* 3.) *A* be the *Sun*, *B* *Jupiter*, *C* the first Satellit of *Jupiter*, which enters into the shadow of *Jupiter*, to come out at *D*, and let *E F G H K L* be the *Earth*, placed at divers distances from *Jupiter*.

Now suppose the *Earth*, being in *L* towards the second Quadrature of *Jupiter*, hath seen the first Satellit, at the time of its emersion, or issuing out of the shadow at *D*, and that about $42\frac{1}{2}$ hours after (*viz.* after one Revolution of this *Satellit*) the *Earth* being in *K*, do see it returned in *D*: It is manifest, that if the Light require time to traverse the Interval *L K*, the *Satellit* will be seen returned later in *D*, than it would have been if the *Earth* had remained in *L*. So that the Revolution of the *Satellit* being thus observed by the Emersions, will be retarded

Digitized by Google

ded by so much time, as the Light shall have taken in passing from *L* to *K*; and that on the contrary, in the other Quadrature *FG*, where the *Earth* by approaching goes to meet the Light, the Revolutions of the Emersions will appear to be shortned, by so much as those of the Emersions had appear'd to be lengthned. And because 42½ hours, which this *Satellit* very near takes to make one Revolution, the distance between the *Earth* and *Jupiter*, in both the Quadratures, varies at least 210 Diameters of the *Earth*: It follows, that if for the Account of every Diameter of the *Earth* there were required a Second of Time, the Light would take 3½ Minutes for each of the Intervals *GF*, *KL*; which would cause near half a quarter of an Hour between two Revolutions of the first *Satellit*, one observed in *FG*, and the other in *KL*, whereas there is not observed any sensible difference.

Yet doth it not follow hence, that Light demands no time. For after M. *Romer* had examin'd the thing more nearly, he found that what was not sensible in two Revolutions, became very considerable in many being taken together; and that, for Example, forty Revolutions observed on the side *F*, might be sensibly shorter, than forty others observed in any place of the *Zodiack* where *Jupiter* may be met with; and that in proportion of Twenty two for the whole Interval of *HE*, which is the double of the Interval that is from hence to the Sun.

The Necessity of this new Equation of the retardment of Light, is established by all the Observations that have been made in the *Royal Academy*, and in the *Observatory*, for the space of eight Years; and it hath been lately confir-

Digitized by Google

med by the Emerſion of the firſt *Satellit* obſerved at *Paris*, the *9th* of *Novembor* laſt, at 5 a-clock 35′ 45″ at night, 10 minutes later than it was to be expected, by deducting it from thoſe that had been obſerved in the Month of *Auguſt*, when the *Earth* was much nearer to *Jupiter*; which M. *Romer* had predicted to the ſaid Academy from the beginning of *September*.

But to remove all doubt, that this Inequality is cauſed by the retardment of the Light, he demonſtrates, that It cannot come from any Excentricity or other cauſe of thoſe that are commonly alledged to explicate the Irregularities of the *Moon*, and the other Planets; tho' he be well aware, that the firſt *Satellit* of *Jupiter* was excentrick; and that, beſides his Revolutions were advanced or retarded, according as *Jupiter* did approach to or recede from the Sun; as alſo, that the Revolutions of the *Primum Mobile* were unequal: Yet, ſaith he, theſe three laſt cauſes of Inequality do not hinder the firſt from being manifeſt.

An

Digitized by Google

An introductory Eſſay *to the Doctrine of* Sounds, *containing ſome Propoſals for the improvement of* Acouſticks; *As it was preſented to the* Dublin Society, *Nov.* 12. 1683, *by the Right Reverend Father in God* Narciſſus *Lord Biſhop of* Ferns *and* Leighlin.

BEing to treat of the Doctrine of *Sounds*, I hold it convenient to premiſe ſomething in the general concerning this Theory; which may ſerve at once to ingage your Attention, and excuſe my pains, when I ſhall have recommended them, as beſtow'd on a Subject not altogether uſeleſs and unfruitful.

And for this purpoſe I ſhall omit to ſpeak any thing of the *Excellency* of the Matter in Hand; tho' it might be celebrated by Arguments drawn from ſeveral Topicks, and particularly from this, that new Diſcoveries and Improvements may be made both as to the *Generation*, *Propagation* and *Reception* of Sounds into the Senſe; which, in a peculiar manner agrees to this, above the Object of any other Senſe whatſoever. I ſhall, I ſay, omit theſe things, and apply my ſelf wholly to the *Uſefulneſs* of the Theory, that we are now falling upon; which I think cannot better be diſcovered, than by making a compariſon 'twixt the Senſes

Digitized by Google

Senſes of *Seeing* and *Hearing* as to their Improvements. I mean, by ſhewing, that this latter of *Hearing* is capable of all thoſe improvements which the Senſe of *Seeing* has receiv'd from Art, beſides many more advantages that the *Ear* may enjoy, by the help of our Doctrine, above the *Eye*; all which moreover will be of as great benefit to Mankind, as any thing that *Opticks* have yet diſcover'd, if not of greater; which, with ſome other preeminencies that it has upon another Score, will happily render *Acouſticks* the nobler Science of the two.

In order to the making good what I but now promiſed of the Compariſon of theſe two Faculties of *Seeing* and *Hearing*, as to their Improvements, I obſerve,

That *Viſion* is threefold, *Direct*, *Refracted*, and *Reflex'd*; anſwerable whereunto we have *Optick*, *Dioptricks*, and *Catoptricks*.

In like manner *Hearing* may be divided into *Direct*, *Refracted* and *Reflex'd*; whereto anſwer three parts of our Doctrine of *Acouſticks*, which are yet nameleſs, unleſs we call them *Acouſticks*, *Diacouſticks*. and *Cathacouſticks*, or (in another Senſe, but to as good Purpoſe) *Phonicks*, *Diaphonicks*, and *Cataphonicks*.

1. Direct Viſion has been improv'd two ways, *ex parte* Objecti, and *ex parte* Organi *vel* Medii.

1. *Ex parte Objecti* Direct Viſion has receiv'd advantages by the Arts of *Producing*, *Conſerving* and *Imitating Light* and *Colours*, which are the Objects of Viſion.

1. For the Art of *Producing Light*, we have the Frication of all hard Bodies that beget Fire; eſpecially of the Flint and Steel; and inſtead

instead of the Flint, most hard Stones (as well as the Cane) may be us'd to the same effect, as upon trial I have found. Add hereto the lately invented *Phosphorus*, which is a new and admirable way of producing a *Lucid Substance* by Art, out of a Body in itself not *Lucid*; and therefore may not unfitly be term'd an *Artificial production* of *Light*.

And then of the Art of *Conserving Light*, the *Lapis Bononiensis* is a notable instance; and so happily were the *Sepulchral Lamps* of the Ancients.

2. As to *Colours*, 'tis the greatest part of the Art of *Dying* to be able to make and fix (that is preserve) them; and the *Painters* and *Limners* will own it to be no small part of their Skill to be able well to *Mix* (that is, in effect, to *Generate*) *Colours*.

3. For *Imitation of Light* and *Colours*, 'tis well known how far *Perspective* with the Art of *Limning* and *Shadowing* have gone therein, which all tend some way to the Advance or Improvement of *Direct Vision*.

Add to all these, That *a due Application of Light to the Object* renders it Visible, if it were not so before; as appears from a dark Room illuminated; or else makes it better and more truly discernable by the Sense of *Seeing*, if before it might have been discern'd.

Hence the same *Colour*, in a divers Light, will appear different, and no *Picture* can well be discern'd or judg'd of but by its true Light. Besides, the *Limner* will assure you, that he can hardly make true Work or hit the Air of a Face exactly, unless we draw by a *North-Light*, by reason of the Steddiness of that, and the uncertainty of all other Lights whatsoever.

Which

Digitized by Google

Which things ſhew, that the *Art of duly applying Light to the Object* does very much help and improve Viſion. So alſo does the due placing of the *Object*, as to *Height* and *Diſtance*. But to enumerate all things that help *Direct Viſion*, would be infinite.

2. *Ex parte Organi vel Medii* Direct Viſion has been improv'd by making uſe of a *Tube*, without Glaſſes, or a Man's clos'd Hand, to look thro'; which admitting into the *Eye* only the principal Rays, that come directly from the Object, do very much ſtrengthen and clear the Sight, by excluding all the Collateral Rays, that crouding into the Eye, together with the direct ones, would confound and diſturb it, partly by mixing and interfering with the Direct Rays, and partly (or rather chiefly) by too much enlightning the fund of the Eye, wherein Viſion is truly (tho' then imperfectly) made.

On this is founded the Art of making *Spectacles* without Glaſſes; (as well as *Tubes*) which is done by putting into the Glaſs-holes (inſtead of Glaſſes) two ſhort *Tubes* of between three and four Inches long (for their length is to be vary'd according to the Age or Eye of the beholder, and ſo alſo is the Diameter of the extream ends) which *Tubes* being made of *Spaniſh Leather* (or Paſt-board, or ſome ſuch like matter) and black'd on the inſide, are ſo to be plac'd, as that the viſual Rays, receiv'd thro' them, may meet in one Point (or rather iſſue out from one Point) of the Object ſtanding at ſuch a due diſtance, as the Perſon may clearly and diſtinctly ſee it, or according to his length of Sight (as ABC, in the 4th Fig. *Tab.* 3.)

And

Digitized by Google

And theſe *Spectacles* may be ſuppos'd better for preſerving the Sight, than the ordinary ones with Glaſſes, becauſe they repreſent the Object more naturally, and withal more clearly and diſtinctly to the Eye, than the other, whoſe refracted Rays being collected together with the right ones in the Glaſſes, do ſomewhat confound good Viſion, as before: Eſpecially if the viſive Power be ſtrong enough to be ſufficiently determin'd by the right Rays alone.

For I ſpeak now of preſerving a good Eye by theſe Spectacles, which holds in proportion *true* alſo of a bad one. Becauſe thoſe Rays (both right and refracted) being collected and brought ſo near the Eye (whether good or bad) as the Spectacles are uſually plac'd, do too much affect it, both by their own brightneſs, and alſo by the brightneſs of the Colours of the Object (when they are bright) which is brought very near alſo; whereby the Eye is dazl'd and confounded, unleſs there be a ſtrong attention and *conatus* of the Spirits, whereto the bright Rays do certainly engage them, which of neceſſity weakens Viſion, eſpecially if theſe Glaſs-ſpectacles be much us'd.

Wherefore the now deſcrib'd new Tube-ſpectacles, contributing ſo much to the help and preſervation of Sight, may well be counted an improvement of *Direct Viſion*, becauſe they convey the Rays to the Eye without any kind of refraction whatſoever. Seeing the ſame Object alſo through various holes, plac'd at certain diſtances, does ſomewhat alter Viſion; but of this perhaps more hereafter.

Now as *Direct Viſion* has thus been improved, ſo likewiſe *Direct Hearing* partly has already receiv'd, and partly may (by the Doctrine whereof

whereof we are treating, (if well cultivated) farther receive as great and notable Improvements, both *ex parte* Objecti, and *ex parte* Organi *vel* Medii.

1. As to the *Object* of Hearing, which is Sound, improvement has been and may be made, both as to the *Begetting*, and as to the *Conveying* and *Propagating* (which is a kind of *Conſerving*) of Sounds.

1. As to the *Begetting* of Sounds. The Art of imitating any Sound, whether by *Speaking* (that is pronouncing) any any kind of Language, (which really is an Art, and the *Art of ſpeaking* perhaps one of the greateſt) or by *Whiſtling*, or by *Singing* (which are allow'd Arts) or by *Hollowing* or *Luring* (which the Huntſman or Faulkner would have to be an Art alſo) or by imitating with the Mouth (or otherwiſe) the Voice of any Animal, as of *Quails*, *Cats*, and the like, or by *Repreſenting* any Sound begotten by the Colliſion of Solid Bodies, or after any other manner; theſe are all *Improvements* of *Direct Hearing*, and may be improv'd.

Moreover the Skill to make all ſorts of *Muſical Inſtruments*, both Ancient and Modern, whether *Wind* Inſtruments or *String'd*, or of any other ſort, whereof there are very many (as *Drums*, *Bells*, the *Syſtrum* of the *Egyptians*, and the like) that beget (and not only propagate) Sounds; the Skill of making theſe, I ſay, is an Art, that has as much improv'd *Direct Hearing*, as an Harmonious Sound exceeds a ſingle and rude one, that is, an immuſical *Tone*; which Art is yet capable of farther improvement. And I do hope, that by the Rules, which may happily be laid down, concerning the *Nature*, *Propagation* and *Proportion* or *Adapting*

dapting of Sounds, a way may be found out, both to improve *Muſical Inſtrumeuts* already in uſe, and to invent new ones, that ſhall be more ſweet and luſhious, than any yet known. Beſides that, by the ſame means *Inſtruments* may be made, that ſhall imitate any ſound in Nature, that is not Articulate, be it of Bird, Beaſt, or what thing elſe ſoever.

2. The *Conveying* and *Propagating* (which is a kind of *Conſerving*) of Sounds, is much help'd by *duly placing the Sonorous Body*, and alſo by the *Medium*.

For if the Medium be *Thin* and *Quieſcent*, and the Sounding Body *plac'd conveniently*, the Sound will be eaſily and regularly propagated, and mightily conſerv'd. I ſay,

1. If the *Medium be thin and Quieſcent*, becauſe it otherwiſe cauſes a *Refracted Sound*, of which afterwards. Hence in a *ſtill Evening* or the *dead of the Night* (when the Wind ceaſes) a Sound is better ſent ont and to a greater diſtance than otherwiſe, tho' much of this may be aſcrib'd to it's *Refraction* alſo.

2. I ſay, that the *Sonorous Body muſt be plac'd conveniently*, near a *Smooth Wall*, near *Water*, or *a Plain*, whoſe Surface is even.

1. Near *a Smooth Wall*, either Plain or Arch'd (Cycloidically or Elliptically, rather than otherwiſe, tho' a Circular or any Arch will do, but not ſo well.)

Hence in a Church, the nearer the Preacher ſtands to the Wall (and certainly 'tis much the beſt way to place Pulpits near the Wall) the better is he heard, eſpecially by thoſe who ſtand near the Wall alſo, though at a greater diſtance from the Pulpit; thoſe at the remoteſt end of the Church, by laying their Ears ſomewhat

Digitized by Google

what cloſe to the Wall, may hear him eaſier than thoſe in the middle.

Hence alſo do ariſe *Whiſpering Places.* For the Voice being apply'd to one end of an Arch, eaſily rowls to the other. And indeed were the *motion* and *propagation* of Sounds but rightly underſtood, 'twould be no hard matter to contrive *Whiſpering Places* of infinite variety and uſe. And perhaps there could be no better or more pleaſant hearing a *Conſort of Muſick* than at ſuch a place as this, where the Sounds rowling along together, before they come to the Ear, muſt needs conſolidate and imbody into one; which becomes a true compoſition of Sounds, and is the very Life and Soul of Conſort.

2. If the Sonorous Body be plac'd near *Water* the Sound will eaſily be convey'd, yet mollified; as Experience teacheth us from a Ring of *Bells* near a River and a great *Gun* ſhot off at Sea, which differ much in the ſtrength, and yet ſoftneſs and continuance or propagation of their Sounds, from the ſame at Land, where the Sound is more harſh and more periſhing, or much ſooner decays.

3. In a *Plain* a Voice may be heard at a far greater diſtance than in uneven Ground.

The *Reaſon* of all which laſt nam'd *Phænomena* is the ſame, becauſe the Sonorous Air meeting with little or no reſiſtence upon a *Plane* (much leſs upon an Arch'd) ſmooth Superficies eaſily rowls along it, without being let or hindred in its Motion, and conſequently without having its parts disfigured, and put into another kind of Revolution, than what they had at the firſt begetting of the Sound. Which is the true cauſe of its *Preſervation* or *Progreſſion*, and fails much when the Air paſſes over an uneven

Digitized by Google

even Surface, according to the degrees of its inequality, and ſomewhat alſo, when it paſſes over the plain Superficies of a Body that is hard and reſiſting.

Wherefore the ſmooth top of the Water (by reaſon of its yielding to the Arch'd Air, and gently riſing again with a kind of reſurge, like to *Elaſticity*, tho' it be not ſo, by which reſurge it quickens and haſtens the motion of the Air rowling over it, and by its yielding preſerves it in its Arch'd Cycloidical or Eliptical Figure) the ſmooth top of the Water, I ſay, for theſe reaſons, and by theſe means, conveys a Sound more entire and to a greater diſtance than the plain Surface of a piece of Ground, a Wall, or any other Solid Body whatever can do.

As for the *Speaking Trumpet*, by which a Voice may be convey'd to a conſiderable diſtance, I refer its conſideration to that of *Refracted Sounds* or *Refracted Audition*.

Thus much of the Improvements of Hearing, that reſpect its *Object* which is *Sound*.

2. The *Organ* and *Medium* are to be conſidered. And, 1. The *Organ*, which is the *Ear*, is helpt much by placing it near a Wall (eſpecially at one end of an Arch, the Sound being begotten at the other) or near the Surface of Water, or of the Earth, along which the Sounds are moſt eaſily and naturally convey'd, as was before declar'd. And 'tis incredible how far a Sound made upon the Earth (by the trampling of a Troop of Horſes, for Example) may be heard in a ſtill Night, if a Man lays his Ear cloſe to the Ground in a large Plain.

Digitized by Google

Otacouſticks here come in for helping the *Ear*; which may be ſo contriv'd (by a right underſtanding the *Progreſſion of Sounds*, which is the principal thing to be known for the due regulating all ſuch kinds of Inſtruments) as that the Sound might enter the Ear without any Refraction, but as now they are generally made. I refer them to *Refracted Audition.*

2. As to the *Medium*, I know not how that, by any contrivance of Art, can advantage *Direct Hearing*, otherwiſe than I have declar'd already in the propagation or conveiance of Sounds, tho' to the Refacting or Reflecting of them it may very much conduce; of which preſently.

And ſo I have done with the firſt part of my preſent undertaking, which is the *Compariſon of Direct Viſion and Audition*, as to their Improvements from Art. The reſt follow. Wherefore;

II. Concerning *Refracted Viſion* and its Compariſon, I obſerve, That *Refracted Viſion* is always made *Ex parte Medii*, as *Reflected* is *ex parte Objecti.* And therefore tho' *Direct Viſion* may be help'd *ex parte Objecti, Medii vel Organi*; yet *Refracted* can be improv'd only *ex parte Medii*, and *Reflected ex parte Corporis oppoſiti* alone. Unleſs it be in a mixt or compound Viſion, that is *Refracto-Reflext*, when the reflext Rays paſs to the Eye through a refracting Medium, ſuch as the Medium Internum, contain'd in the Body of the Eye always is. So that in truth all Viſion is *Refracted* by an internal Refraction made in *ipſo Oculo.*

And

Digitized by Google

And all that I have spoken of *Vision* holds true of *Hearing* also, both *Refracted* and *Reflext*, and therefore need not be repeated.

Refracted Vision arises from the different *Density*, *Figure* and *Magnitude* of the Medium, which is somewhat alter'd also by the divers incidence of the visible Rays. And so it is in *Refracted Hearing*, all these Causes concur to its Production, and some others to be hereafter consider'd.

Now as any Object (a Man for example) seen through a thicken'd Air, by *Refraction* appears greater than really he is: So likewise a *Sound*, heard through the same thickned part of the *Atmosphere*, will be considerably vary'd from what it would seem to be, if heard through a thinner Medium.

And this I call a *Refracted Sound*: But what this Refraction of Sound is, and how caus'd, may hereafter be discuss'd, when the Nature, and Motion, or Progression of Sounds are well stated.

For the Improvement of *Refracted Vision* artificial Instruments have been made, by grinding or blowing Glasses into a certain Figure, and placing them at due distances, whereby the Object may be (as 'twere) enabled to send forth its Rays more vigorously, and the Visive Faculty impower'd the better to receive them. And thus also Instrumnents may be contriv'd for the assisting both the *Sonorous Body*, to send forth its Sound more strongly, and the *Acoustick Faculty* to receive and discern it more easily and clearly. *For*,

1. As a fine *Glass Bubble*, fill'd with clear Water, and plac'd before a burning Candle or Lamp, does help it to dart forth its Rays to a

Digitized by Google

prodigious length and brightneſs: So an *Inſtrument* may be invented, that apply'd to the Mouth (or any Sonorous Body) ſhall ſend forth the Voice diſtinctly to as prodigious a diſtance and loudneſs.

For if the *Stentoro-phonecon* (which is but a rude and unartificial Inſtrument) does ſuch great feats, what might be done with one compos'd according to the Rules of Art? whoſe make ſhould comply with the Laws of *Sonorous Motion* (which that does not) and therefore not ſo much *Refract*, as to alter and confound the *Tone* of *the Voice* and Words (as that ſomewhat does.)

Now of what uſe ſuch an Inſtrument might be for ſpeaking clearly and articulately at a diſtance (and that without altering the Tone of the Voice) whether it be at Sea or at Land (but eſpecially at Sea in tempeſtuous Weather and in the Night) is obvious to any Man to conceive.

2. As Inſtruments have been invented to help the Eye, So likewiſe are there ſome, and more ſuch there may be for the Ear.

For,

1. As *Spectacles* and other *Glaſſes* are made to help the *Purblind* and weak *Eyes*, to ſee at any competent diſtance: So there are *Otacouſticks* (and better may be made) to help weak *Ears* to hear at a reaſonable diſtance alſo. Which would be as great a help to the infirmity of Old Age, as the other invention of Spectacles is, and perhaps greater; foraſmuch as the Hearing what's ſpoken is of more daily uſe and concern to ſuch Men, then to be able to *read Books* or to *view Pictures.*

2. As

Digitized by Google

2. As *Perſpective-Glaſſes* and Teleſcopes help the Eye to ſee Objects at a very great diſtance, which otherwiſe would not be diſcernable; in like manner may a ſort of *Otacouſticks* be ſo contriv'd as that they ſhall receive in *Sounds* made at a very great diſtance alſo, but with ſo much advantage, that the Ear ſhall be able to hear them, which otherwiſe would have been *inaudible.*

And theſe *Otacouſticks* in ſome reſpects would be of greater uſe than *Perſpectives.* For whereas at Land *Perſpectives* are many times render'd almoſt uſeleſs, by the interpoſition of Woods and Mountains, which hinder the Sight from reaching very far: Our *Otacouſticks* would, notwithſtanding theſe Obſtacles, take in a Sound made ſome Leagues off. Which might be of notable uſe in the time of War, for diſcovering the Enemy at a good diſtance, when he marches or lyes incamp'd behind a Mountain or Wood, or any ſuch place of ſhelter.

Yea even at Sea alſo, where *Perſpectives* are of moſt uſe, by reaſon of the plaineſs of the Surface of the Water; yet ſometimes there *Otacouſticks* may be of more benefit, when in dark hazy Weather the Air is too thick, or in Stormy Tempeſtuous Weather the Waves a riſe too high for the *Perſpective* to be made uſe of.

But whether at Sea or Land *Perſpectives* become altogether inſignificant in the Night-time (unleſs it be for viewing the Stars) which is the chief time for uſing *Otacouſticks*; as it is generally, for Souldiers to take their March, when they would ſurpriſe their Enemies.

And therefore this ſort of *Otacouſticks* have then their chief uſe, when *Perſpectives* are of no

Digitized by Google

uſe at all; beſides that they may be imploy'd in the Day-time, as well as *Perſpectives*, whence they may (not unfitly) be term'd *the moſt uſeful Inſtrument* of the two.

3. As *Miſcoſcopes* or *Magnifying-Glaſſes* help the Eye to ſee near *Objects*, that by reaſon of their ſmallneſs were *Inviſible* before; which Objects they Magnify to a ſtrange greatneſs: So *Microphones* or *Micracouſticks*, that is Magnifying Ear Inſtruments may be contriv'd after that manner, that they ſhall render the moſt minute Sound in nature diſtinctly audible, by Magnifying it to an unconceivable loudneſs.

By the help hereof we may here the different Cries and Tones, as well as by *Microſcopes* ſee the divers Shapes and Figures of the ſmalleſt Animals.

4. As by *Polyſcopes* or *Multiplying-Glaſſes*, one thing is repreſented to the Eye as many, whether in the ſame or different Shapes (for ſo Multiplying-glaſſes may be contriv'd:) So by a *Polyphone* or *Polyacouſtick* well order'd one *Sound* may be heard as many, either of the ſame or a different Note. Inſomuch, that who uſes this Inſtrument, he ſhall, at the Sound of a ſingle Viol, ſeem to hear a whole Conſort and all true Harmony. By which means this Inſtrument has much the advantage of the *Polyſcope*.

And thus much may ſuffice for compairing the Improvenments made upon *Refracted Seeing and Hearing*; I call it *Refracted Hearing*, becauſe made throngh a *Medium*, viz. thick Air or an Inſtrument, through which the Sound paſſing is broken or refracted.

III. *Reflected*

Digitized by Google

III. *Reflected Vision* has been improv'd by the Invention of *Looking-glasses* and *Polish'd Metals*, whether *Plane*, *Concave*, or *Convex*; and these two last, either *Spherical*, *Oval*, *Cylindrical*, *Conical*, *Hyperbolical*, or of several other shapes; all which cause a different Reflection, and vary the *Phænomena*.

Thus also *Reflex'd Audition*, made by *Ecchoes*, may be improv'd, by contriving several sorts of *Artificial Ecchoes*; as 'tis no hard matter to do in almost any place.

For (speaking in the general) *Any Sound, falling directly or obliquely upon any dense Body, of a smooth (whether Plane or Arch'd) Superficies, is beat back again and reflected, or does eccho more or less.*

I say (1.) *falling directly or obliquely*; because, if the Sound be sent out and propagated *parallel* to the Surface of the *Dense Body*, or be made so *far off* and so *weak*, that it cannot reach it, there will be no reflection of Sound, no *Eccho*.

I say (2.) *upon a Body of a smooth Superficies*; because if the Surface of the *Corpus Obstans* be uneven, the Air by reverberation will be put out of its regular Motion, and the Sound thereby broken and extinguish'd: So that tho' in this case also the Air be beaten back again, yet Sound is not reflected, nor is there any Eccho.

I say (3) *it does eccho more or less*, to shew, that when all things are, as is before describ'd, there is still an Ecchoing, though it be not always heard; either because the *direct Sound* is too weak to be beaten quite back again to him that made it; or that it does return home to him, but so weak, that without the help of a good *Otacoustick* it cannot be discern'd; or that

Digitized by Google

he ſtands in a wrong place to receive the reflected Sound, which paſſes over his head, under his Feet, or to one ſide of him; which therefore may be heard by a Man ſtanding in that place, where the reflected Sound will come, provided no interpos'd Body does intercept it; but not by him, that firſt made it.

I ſhall further make out the compariſon 'twixt *Reflex'd Viſion* and *Audition*, by theſe following *Propoſitions.*

1. As a *Plane Speculum* reflects the *Object* in its due *Dimenſions* and *Colours*; allowing for their difference of appearance according to their diſtance: So a *Plane Corpus Obſtans* reflects the *Sound* back in its due *Tone* and *Loudneſs*; if allowance be likewiſe made for the proportionable decreaſe of the Sound according to its diſtance.

2. As a *Convex Speculum* reflects the Object *leſs*, but ſomewhat *brighter* or clearer: So a *Convex Corpus Obſtans* repels the Sound (inſenſibly) *ſmaller*; but ſomewhat *quicker* (though *weaker*) than otherwiſe it would be.

3. As a *Concave Speculum* reflects the Object *bigger*, more *obſcure* and *Inverted*: So a *Concave Corpus Obſtans* ecchoes back the Sound (inſenſibly) *bigger*, *ſlower* (though *ſtronger*) and alſo *inverted*; but never according to the order of Words. Nor do I think it poſſible for the Art of Man to contrive a *Single Eccho*, that ſhall invert the Sound and repeat backwards; becauſe then the Words laſt ſpoken, that is, which do laſt occurr to the *Corpus Obſtans*, muſt firſt be repell'd; which cannot be: For where in the mean time ſhould the firſt Words hang, and be conceal'd, or lie dormant? Or how, after ſuch a pauſe, be reviv'd and animated again into

Digitized by Google

into Motion? Yet in complicated or *Compound Ecchoes*, where many receive from one another, I know not whether something that way may not be done.

From the determinate *Concavity* or *Archedness* of these reflecting Bodies, it comes to pass, that some of them, from a certain distance or posiure, will eccho back but one determinate Note, and from no other place will they reverberate any; because of the undue Position of the sounding Body. Such an one (as I remember) is the Vault in *Merton* College in *Oxford*.

4. As a *Speculum* takes in and reflects more of its Object, when plac'd at a great distance from it, than when nearer; because it reflects according to the apparent Magnitude of the Body at such a distance, which is less: So also the *Ecchoing Body*, being removed farther off, reflects more of the Sound, than when nearer. And this is the reason, why some Ecchoes repeat but one Syllable, some one Word, and some many.

5. As *Specula's* may be so plac'd, that reflecting one upon or into the other, either directly or obliquely, one Object shall appear many; as in Sir *Samuel Moreland*'s Glass-room: After the same manner *Ecchoing Bodies* may be so contrived and plac'd, as that reflecting the Sound from one to the other, either directly and mutually, or obliquely and by Succession, out of one Sound shall many Ecchoes be begotten; which in the first case will be all together, and somewhat involv'd or swallow'd up of each other, and thereby confus'd (as a Face in Looking-glasses obverted) in the other they will be distinct, separate, and succeeding one another; as most *multiple Ecchoes* do.

Moreover

Digitized by Google

Moreover a *Multiple Eccho* may be made, by ſo placing the *Ecchoing Bodies*, at unequal diſtances, that they reflect all one way, and not one on the other; by which means a manifold ſucceſſive Sound will be heard (not without aſtoniſhment) one clap of the hands like many, one ha like a laughter, one ſingle word like many of the ſame tone and accent, and ſo one Viol like many of the ſame kind imitating each other.

Furthermore, as *Specula's* may be ſo order'd, that by Reflection they ſhall make one ſingle thing appear many different things; as one ſingle Man to ſeem many Men, differing as to ſhape and Complexion (or a company of Men) which I think Sir *Samuel Moreland*'s Contrivance does not: So may *Ecchoing Bodies* alſo be order'd, that from any one Sound given, they ſhall produce many Ecchoes, different both as to their *Tone* and *Intenſion*. (The ground whereof has elſewhere been laid down in a Treatiſe concerning the *Sympathy of Lute-ſtrings*.)

By this means a *Muſical Room* may be ſo contriv'd, that not only one Inſtrument, play'd on in it ſhall ſeem many of the ſame *ſort* and *ſize*; but even a Conſort of (ſomewhat) different ones; only by placing certain *Ecchoing Bodies* ſo, as that any Note (play'd) ſhall be return'd by them in 3ds, 5ths, and 8ths, which is poſſible to be done otherwiſe than was mention'd before in *Refracted Audition*.

I have now done with my *Compariſon* of the two Nobleſt *Senſes* and *Sciences*, as to their *Improvements*; wherein I have been thus large, that I might give you a little proſpect into the *Excellency* and *Uſefulneſs* of *Acouſticks*; and that thereby I might excite all that hear me, to bend their

Digitized by Google

their Thoughts towards the making of Experiments for the compleating this (yet very imperfect, though noble) Science; a *Specimen* whereof I will give you in three *Problems*, and then present you with the *Semiplane* of *an Acouſtick or Phonical Sphere*, as an Attempt to explicate the great *Principle* in this Science, which is *The Progreſſion of Sounds.*

The Problems are theſe:

1. *Sonum intendere quouſque velis*; or, *Datum ſonum ad datum gradum intendere.*

2. *Sonum extendere quouſqus velis*; or, *Datum ſonum ad datam diſtantiam extendere ſeu propagare.*

3. *Sonum tranſire ab extremo ad extremum & non per Medium.*

1. The firſt is, *To make the leaſt Sound* (by the help of Inſtruments) *as loud as the greateſt*; a whiſper to become as loud as the ſhot of a Canon.

By the help of this *Problem*, the moſt minute Sounds in Nature may be clearly and diſtinctly heard.

2. The ſecond is, *To propagate any* (the leaſt) *Sound to the greateſt diſtance.*

By the help hereof any Sound may be convey'd to any, and therefore heard at any diſtance, (I muſt add, within a certain, though very large Sphere.)

Moreover, by this means, a *Weather-cock* may be ſo contriv'd, as that with an ordinary blaſt of Wind it ſhall cry (or whiſtle) loud enough to be heard many Leagues: Which happily may be found of ſome uſe, not only for *Pi-*

lots

Digitized by Google

lots in mighty tempeſtuous Weather, when *light Houſes* are render'd almoſt uſeleſs; but alſo for the meaſuring the ſtrength of Winds, if allowance be made for their different moiſture. For I conceive, that the more dry any Wind is, the louder it will whiſtle *cæteris paribus*; I ſay, *cæteris paribus*, becauſe, beſides the ſtrength and and dryneſs of Winds or Breath, there are a great many other things (hereafter to be conſider'd) that concur to the increaſe or magnifying of Sounds, begotten by them in an Inſtrument expoſed to their violence, or blown into.

3. The third *Problem* is, *That a Sound may be convey'd from one extreme to the other* (or from one diſtant place to another) *ſo as not to be heard in the middle.*

By the help of this *Problem* a Man may talk to his Friend at a very conſiderable diſtance, ſo that thoſe in the middle ſpace ſhall hear nothing of what paſſed betwixt them.

FIG. V. TAB. III.

Semiplanum Sphæræ Phonicæ ſeu Acouſticæ.

You are to conceive that (rude) *Semiplane*, as parallel to the *Horizon*: For if it be perpendicular thereunto, I ſuppoſe the upper extremity will be no longer *Circular*, but *Hyperbolical*, and the lower part of it ſuited to a greater Circle of the Earth. So that the whole *Phonical* Sphere (if I may ſo call it) will be a ſolid *Hyperbola*, ſtanding upon a *Concave Spherical* Baſe. I ſpeak this concerning *Sounds* made (as uſually they are) nigh the Earth,

Digitized by Google

Earth, and whoſe Sonorous *Medium* has a free paſſage every way. For if they are generated high in the Air, or directed one way, the caſe will be different; which is partly deſign'd in the inequality of that draught.

Digitized by Google

A Diſcourſe concerning the Modern Theory *of* Generation, *by Dr.* George Garden *of* Aberdeen, *being part of a Letter to Dr.* William Muſgrave, *L. L. D. Reg. Soc. S. and by him communicated to the Royal Society.*

THE Subject I pitch upon, is that of the ~~Formation of Animals. You know how~~ wide and unſatisfying Mens Conjectures were upon this Head, until this Age, in which firſt the deſervedly Famous Dr. *Harvey* diſcovered the proper place of the Formation of the Chick in the *Cicatricula* of the Egg, and the Formation of the Parts ſo far as was diſcernable by the naked Eye; and after him *Malpighius*, by the help of exact Glaſſes, obſerved the firſt Rudiments of it there, both before and after Incubation: And *R. de Graef*, and others, having upon many Obſervations concluded, that the *Teſtes Fœminei* were the Ovaries of Females, and conſequently that all Animals were *ex ovo*; they began from hence to infer, that the Rudiments of each Animal were originally in the reſpective Females, and that the Male contributed only to give a new Ferment to the Maſs of the Blood and Spirits, by which means a ſpirituous Liquor (which the Blood in its ordinary Ferment could not produce) did inſinuate its ſelf into the

Digitized by Google

the ſame Ducts and Pores of the Rudiments of thoſe Animals, which were in greateſt forwardneſs in the Ovary, and ſo extend, and enlarge all their Parts, and at laſt bring them to perfection, as Mr. *Perrault* does ingeniouſly diſcourſe in the third Part of his *Eſſais de Phyſique*; till now at laſt *Leowenhoek* has diſcovered an infinite number of *Animalcula in ſemine marium* of all kinds, which has made him condemn the former Opinions about the Propagation of all Animals *ex Ovo*.

Now upon comparing the Obſervations and Diſcoveries which have been made with one another, theſe three things ſeem to me very probable. 1. That Animals are *ex Animalculo*. 2. That theſe Animalcles are originally *in ſemine Marium & non in Fœminis*. 3. That they can never come forward, nor be formed into Animals of the reſpective kind, without the *Ova in Fœminis*.

The firſt of theſe ſeems probable from theſe three Obſervations. 1. That ſome ſuch thing has been ſo often obſerved by *Malpighius*, in the *Cicatricula* of an Egg before Incubation, as the Rudiments of an Animal in the ſhape of a Tadpole, as may be ſeen in his firſt, and in his repeated Obſervations *de formatione Pulli in Ovo*. 2. The ſudden appearance and diſplaying of all the Parts after Incubation, makes it probable, that they are not then actually formed out of a fluid, but that the *Stamina* of them have been formerly there exiſtent, and are now expanded. The firſt Part of the Chick which is diſcovered with the naked Eye, is, you know, the *Punctum ſaliens*, and that not till three days and nights of Incubation be paſt; and then, on the

Digitized by Google

the fifth day, the Rudiments of the Head and Body do appear. This made Dr. *Harvey* conclude, that the Blood had a being before any other Part of the Body; and that from it, all the Organs of the *Fœtus* were both form'd and nouriſhed: But by *Malpighius*'s Obſervations we find that the Parts are then only ſo far extended, as to be made viſible to the naked Eye, and that they were actually exiſtent before, and diſcernable by Glaſſes. After an Incubation of thirty hours, are to be ſeen the Head, the Eyes, and the *Carina*, with the *Vertebræ*, diſtinct, and the Heart. After forty hours its Pulſe is viſible, and all the other Parts more diſtinct, which cannot be diſcerned by the naked Eye before the beginning of the fifth day; from whence it ſeems probable, that even the ſo early diſcovery of thoſe Parts of the *Fœtus* by the Microſcope, is not the diſcerning of Parts newly formed, but only more dilated and extended by receiving of Nutriment from the *Colliquamentum*; ſo that they ſeem all to have been actually exiſtent before the Incubation of the Hen. And what *Swammerdam* has diſcovered in the tranſformation of Inſects, gives no ſmall light to this; whilſt he makes appear in the Explanation of the 13th Table of the General Hiſtory of Inſects, that in thoſe large *Eruca's* which feed upon Cabbage, if they be taken about the time they retire to be transform'd into *Aurelia's*, and plung'd often in warm Water to make a Rupture of the outer Skin, you will diſcern thro' the tranſparency of their ſecond Membrane, all the Parts of the Butterfly, the Trunk, Wings, Feelers, *&c.* folded up. But that after the *Eruca* is chang'd into an *Aurelia*, none of theſe Parts can be diſcerned, they are ſo drencht

Digitized by Google

drencht with moisture, tho' they be there actually form'd. Another Consideration is from the Analogy, which we may suppose between Plants and Animals. All Vegetables we see do proceed *ex Plantula*, the Seeds of Vegetables being nothing else but little Plants of the same kind folded up in Coats and Membranes; and from hence we may probably conjecture, that so curiously an organized Creature as an Animal, is not the sudden Product of a Fluid or *Colliquamentum*, but does much rather proceed from an Animalcle of the same kind, and has all its little Members folded up according to their several Joints and Plicatures, which are afterwards enlarged and distended, as we see in Plants. Now tho' this Consideration alone may seem not to bear much weight; yet being join'd to the two former they do mutually strengthen each other. And indeed all the Laws of Motion which are as yet discovered, can give but a very lame account of the forming of a Plant or Animal. We see how wretchedly *Des Cartes* came off when he began to apply them to this Subject; they are form'd by Laws yet unknown to Mankind; and it seems most probable, that the *Stamina* of all the Plants and Animals that have been, or ever shall be in the World, have been formed, *ab Origine Mundi*, by the Almighty Creator within the first of each respective kind. And he who considers the Nature of Vision, that it does not give us the true magnitude, but the proportion of things; and that what seems to our naked Eye but a Point, may truly be made up of as many Parts as seem to us to be in the whole visible World, will not think this an absurd or impossible thing.

Digitized by Google

But the second thing which later Discoveries have made probable, is, that these Animalcules are originally *in Semine Marium & non in fœminis.* And this I collect from these Considerations: 1. That there are innumerable *Animalcula* discovered *in Semine Masculo omnium Animalium.* Mr. *Leewenhoeck* has made this so evident by so many Observations, that I do not in the least question the truth of the thing. The reason of their multitude, and some of the difficulties which arise thereupon, he has cleared to very good purpose, so that I shall not repeat them. 2. The observing the Rudiments of the *Fœtus* in Eggs, which have been fecundated by the Male, and the seeing no such thing in those which are not fecundated, as appears from *Malpighius* his Observations, make it very probable that these Rudiments proceed originally from the Male, and not from the Female. 3. The resemblance between the Rudiments of of the *Fœtus in Ovo*, both before and after Incubation, and the *Animalcule*, makes it very probable that they are one and the same. The same Shape and Figure which Mr. *Leewenhoeck* gives us of the *Animalcule*, *Malpighius* likewise gives of the Rudiments of the *Fœtus*, both before and after Incubation; yea, and even the *Fœtus's* of Animals do appear so at first to the naked Eye, so that Dr. *Harvey* does acknowledge that all Animals, even the most perfect, are begotten of a Worm, *De Gen. Anim. Ex.* 18. 4. This gives a rational account of many *Fœtus's* at one Birth, especially that of the Countess of *Holland*, and how at least a whole Cluster of Eggs in a Hen are fecundated by one Coition of the Male. 5. This gives a new light, as it were, to the first Prophecy concerning the

Messiah,

Digitized by Google

Messiah, that the Seed of the Woman shall bruise the Head of the Serpent, all the rest of Mankind being thus most properly and truly the Seed of the Man. 6. The Analogy I have already mentioned, which we may rationally suppose between the manner of the propagation of Plants and Animals, does likewise make this probable. Every Herb and Tree bears its Seed after its kind; which Seed is nothing else but a little Plant of the same kind, which being thrown into the Earth, as into its *Uterus*, spreads forth its Roots and receives its nourishment, but has its form within its self, and we may rationally conjecture some such Analogy in the Propagation of Animals.

The third Particular which later Discoveries make probable, is, that Animals cannot be form'd of these *Animalcula* without the *Ova in fœminis*, which are necessary for supplying of them with proper Nutriment: And this these Considerations seem to evince. 1. It is probable that an Animalcule cannot come forward, if it do not fall into a proper *Nidus*. This we see is the *Cicatricula* in Eggs; and tho' a Million of them should fall into an Egg, none of them would come forward, but what were in the Center of the *Cicatricula*; and perhaps the *Nidus* necessary for their formation is so proportion'd to their bulk, that it can hardly contain more than one Animalcule; and this may be the reason why there are so few Monsters. This we see is absolutely necessary in *Oviparis*; and the only difference which seems to be between them and the *Vivipara*, in this matter, is in this, that in the latter the *Ova* are properly nothing more but the *Cicatricula*, with its *Colliquamentum*, so that the *Fœtus* must spread forth

Digitized by Google

its Roots into the *Uterus* to receive its nouriſhment; But the Eggs in *Oviparis* may be properly term'd an *Uterus*, in relation to the *Fœtus*; for they contain not only the *Cicatricula*, with its *Amnion* and the *Colliquamentum*, which is the the immediate nouriſhment of the *Fœtus*, but alſo the materials which are to be converted into that *Colliquamentum*; ſo that the *Fœtus* ſpreads forth its Roots no farther than into the white and yolk of the Egg, from whence it derives all its nouriſhment. Now that an Animalcule cannot come forward without ſome ſuch proper *Nidus*, Mr. *Leewenhoeck* will not readily deny; for if there were nothing needful, but their being thrown into the *Uterus*, I do not ſee why many hundreds of them ſhould not come forward at once; for as to what Mr. *Leewenhoeck* ſays, that one of them would be-dwarf and choak the reſt; this might fall out in proceſs of time: But at firſt I do not ſee why many of them ſhould not grow together, whilſt ſcatter'd in ſo large a Field (and yet no ſuch thing is obſerved) if there were not an abſolute neceſſity of a *Cicatricula* for their growth and thriving. Now, 2. That this *Cicatricula* is not originally in *Utero*, ſeems evident from the frequent Conceptions which have been found *extra Uterum*: Such as the Child which continued Twenty ſix years in the Woman of *Tholouſe*'s Belly, mentioned *Numb.* 139. of the *Phil. Tranſ.* And the little *Fœtus* found in the *Abdomen de St. Mere*, together with the Teſticle torn and and full of clotted Blood, recorded *Numb.* 150. both taken out of the Journals *des Scavans*: Such alſo ſeem to be the *Fœtus* in the *Abdomen* of the Woman of *Copenhagen*, mentioned in the *Nouvelles des Lettres*, for *Sept.* 85. *pag.* 996. all the

Digitized by Google

the Members of which were eaſily to be felt thro' the Skin of the Belly, and which ſhe had carried in her Belly for four Years; and the ſeven Years Gravidation, related by Dr. *Cole*, *Numb.* 172. of the *Tranſact.* That theſe two were undoubtedly *extra Uterum*, is uncertain, becauſe the laſt was not opened after her death, and the former may be yet ſtill alive. Now granting once the neceſſity of a proper *Nidus*, for the formation of an Animalcle into the Animal of its reſpective kind; theſe Obſervations make it probable, that the *Teſtes* are the *Ovaria* appropriated for this uſe; for tho' the Animalcles coming thither in ſuch Caſes may ſeem to be extraordinary, and that uſually the Impregnation is *in Utero*; yet it may be collected from hence, that the *Cicatriculæ* or *Ovæ* to be impregnated, are in *Teſtibus fœmineis*; for if it were not ſo, the accidental coming of Animalcles thither could not make them come forward more than in any other part of the Body, ſince they cannot be formed and nouriſhed without a proper *Nidus*. But 3. It is acknowledg'd by all, that the *Fœtus in Utero*, for ſome conſiderable time after Conception, has no connexion with the Womb, that it ſits wholly looſe to it, and is perfectly a little round Egg with the *Fœtus* in the midſt, which ſends forth its Umbilical Veſſels by degrees, and at laſt lays hold on the *Uterus*. Now from hence it ſeems evident, that the *Cicatricula*, which is the Fountain of the Animalcles nouriſhment, does not ſprout from the *Uterus*, but has its *Origin* elſewhere, and falls in thither as into a fit Soil, from whence it may draw Nutriment for the growth of the *Fœtus*; elſe it cannot be eaſily imagin'd, how it ſhould not have an immediate

Digitized by Google

Connexion with the *Uterus* from the time of Conception. If you join all theſe three Conſiderations together, *viz.* that an Animalcule cannot come forward without a proper *Nidus* or *Cicatricula*; that there have been frequent *Fœtus's extra Uterum*; and that they have no *Adhæſion* to the *Uterus*, for a conſiderable time after Conception, they ſeem to make it evident, that Animals cannot be form'd *ex Animalculis* without the *Ova in Fœminis*. To all theſe I ſhall ſubjoin the Propoſal of an *Experimentum Crucis*, which may ſeem to determine, whether the *Teſtes Fœmineæ* be truly the *Ovaria*, *viz.* Open the *Abdomen* of the Females of ſome kinds, and cut our theſe Teſticles, and this will determine, whether they be abſolutely neceſſary for the formation of Animals.

There are ſome Difficulties propoſed againſt this Conjecture, which I think may be eaſily reſolved. Some object the diſtance between the *Tubæ* or *Cornua Uteri*, and the Teſticles; but to this is oppoſed by *Swammerden*, and others, the like diſtance between the *Infundibulum*, in Hens and Frogs, and the Ovary; and yet it cannot be denied that the Eggs are tranſmitted thro' this into the *Uterus*: and beſides *R. de Graef*, and others, have by repeated Obſervations found that the *Cornua Uteri* do at certain times after Conception, embrace the *Teſtes* on both ſides the *Uterus*. They object in the ſecond place the great diſproportion between the pretended Eggs in the Ovary, and the Aperture of the *Tubæ* or *Cornua Uteri*, the former being a great deal bigger than the latter: But both *R. de Graef* and *Malpighius* have clear'd that Matter, by making appear, that theſe Bladders in the Ovary are not the *Ova*, but ſerve to form the *Glandules* within

Digitized by Google

within which the *Ova* are formed, which break through a small *Papilla* opening in the *Glandule*, which bears a proportion to the Aperture of the Tube. They object 3. The difficulty to conceive how these Eggs should be impregnated *per semen Maris*, both because there is no Connexion between the *Tubæ* and the Ovary for its transmission, and for that Dr. *Harvey* could never discover any thing of it in *Utero*. As to the last, Mr. *Leewenhoeck* has cleared that difficulty, by the discovery of innumerable *Animalcula Seminis Maris in Cornubus Uteri*, and those living a considerable time after Coition. *Numb.* 174. of the *Transact.* And as to the former, we may either suppose that there is such an Inflation of the *Tubæ* or *Cornua uteri tempore Coitionis*, as makes them embrace the *Ovaria*, and such an approach of the *Uterus* and its *Cornua*, as that i may easily transmit the Seed into the Ovary; or else, that the *Ova* are impregnated by the Animalcles after they descend into the *Uterus*, and not in the Ovary; the former seems probable for this reason, that at least a whole Cluster of Eggs in a Hen will be fecundated by one Tread of the Cock: Now this Fecundation seems to be in the Vitellary, and not in the *Uterus*, as the Eggs pass along from day to day; for it can hardly be supposed that the Animalcles should subsist so long, being scattered loosely in the *Uterus*, as to wait there for many days for the Fecundation of the Eggs as they pass along. The latter conjecture has this to strengthen it, that the Animalcles are found to live a considerable time in the *Uterus*; and that if they should impregnate the *Ova* in the Ovary its self, the *Fœtus* would increase so fast, that the *Ova* could not pass thro' the *Tubæ Uteri*,

Digitized by Google

but would either burst the Ovary, or fall down into the Abdomen from the Orifices of the *Tubæ*; and that from hence proceed those extraordinary Conceptions in *Abdomine extra Uterum*. But, 4. Mr. *Leewenhoeck*, *Numb.* 147. of the *Transact.* to weaken the third Consideration about the Conceptions, being like unto an *Ovum* in the Womb, proposes a Parallel between these Animalcules and Insects; and insinuates, that as the latter cast their Skins and appear of another Shape, so the other which at first seem like Tadpoles, may cast their outer Skin and and then be round, and that this may be the occasion of the round Figure of the Conception in the Womb. To this it may be replied, that according to Mr. *Leewenhoeck*'s own Sentiment, the Animalcles cannot come forward, if they do not find the *Punctum* or proper place for their Nourishment, to which it seems they must have some *Adhæsion*. Now the Conception in *Viviparis* is not fastned unto the Womb for many days, nor does adhere to any point of it; so that it seems this roundish Body is not the Animalcle thus chang'd after having cast an outer Skin, but is rather the *Cicatricula* or little Egg, into which the Animalcle has entred as its *Punctum* or place of Nourishment; else I do not see why they should not be adhering to the Womb from the first Conception, or why (as I have said) many hundreds of them are not conceived and formed together, *&c.*

Digitized by Google

A short Discourse concerning Concoction: Read at a Meeting of the Royal Society, May 1699, *by* Clopton Havers, *M. D. Fellow of the Royal Society.*

THE manner in which the Digestion of the Aliment is performed, is a thing not very easie to be understood and explain'd. However, it has not escap'd the Conjectures of some Philosophical Men, who having curiously observ'd the *Phænomena* of Nature, and enquired into their Causes, have, amongst other things, endeavour'd to account for this. But their Sentiments about it have been various, and the Hypothesis, by which they have studied to explain it, very different. Some have thought the Concoction of the Food to be a kind of Elixation; and that the grosser and more solid Parts being, as it were, boil'd in the Liquid by the Heat of the Stomach, and the Parts adjacent to it, as the Liver, Spleen, and Omentum, are by a long and continued Elixation first render'd more tender, and then colliquated, and dissolved into minuter Particles, so as to mix more equally with the fluid, and with that to make one Pulpament, or chylous Mass. And *Hippocrates*, tho' he does not plainly call it an Elixation, yet seems to attribute the Concoction of the Food to the Heat of the Stomach, as the Cause of it, *Sect. 4. Libro de Salubri victus ratione.*

Digitized by Google

ratione. So where he takes notice of the voiding of ſuch Fœces, as appear to be like the Food that has been eaten, he adds, *Conſtat enim, ſane ventriculum, ciborum copiam, ut concoquat, calefacere non poſſe.* And there are other Paſſages in the ſame Book, from which we may conclude, that he ſuppos'd the Heat of the Stomach to be the great Cauſe of the Digeſtion of the Food.

There are others that make the Stomach it ſelf to be the great Inſtrument of Digeſtion, but in a different manner: And they ſuppoſe it to be perform'd by an Attrition, as if the Stomach, by thoſe repeated motions, which are the neceſſary Effects of Reſpiration, when it is diſtended by the Aliment, did both rub or grind off ſome minuter Particles from the groſſer Parts, and by continually agitating the Maſs of Food, make thoſe Parts, which are not contiguous to the Stomach, ſtrike one againſt another, and break one another in pieces, until they are all attenuated. It is evident enough, that the ſides of the Stomach do in Expiration preſs upon the Contenta, ſo as to oblige, at leaſt ſome Parts of them, every time the Muſcles of the Abdomen are contracted, to move and ſhift their places. So in Inſpiration, when the Diaphragm and Liver preſs upon the upper part of the Stomach, the Aliment muſt be moved again. So that by theſe reciprocal motions, that part of the Food which is contiguous to the Stomach, and moves in a Line parallel to it, muſt rub againſt it; and all the other Parts being moved by ſuch a Compreſſion, as gives them a different Tendency, it is certain they muſt be continually ſtriking one againſt another. And for Bread, and ſuch things as are made of Flower

Digitized by Google

er, that will be ſoften'd and diſſolv'd with any common Liquid, that Agitation of the Stomach which moves them in Reſpiration, might ſeem ſufficient to break and diſſolve them, when they are ſufficiently moiſten'd with a Fluid. Yet this cannot be thought enough to break and digeſt Fleſh-meat, Fruits, or any other thing that will not be ſoftned and diſſolv'd in Water, or ſome ſuch Liquid. But altho' this Motion of the Aliment, cauſed by Reſpiration, does not actually digeſt it, yet it has a great and neceſſary Uſe in Concoction, and makes all the groſſer Parts, as they are attenuated, mix equally with the Fluid.

Some think that the Bilious Juice; others, that the Spirits are chiefly concern'd in this Affair. *Galen*, in his Book *de Naturalibus Facultatibus*, makes it to be the Effect, not of one, but of ſeveral Cauſes; as a pituitous Juice in the Stomach, the Bile, *&c.* which appears from what he has ſaid, and the Tranſlator thus render'd: ‘*Verum quanto ii (cibi) qui manſi ſunt, iis, qui inhæſerunt, magis ſunt alterati; tanto etiam his magis ii, qui devorati ſunt. Siquidem incomparabilis erit horum alterationis exceſſus, ſi & quæ in ventre eſt Pituita & Bilis, & Spiritus, & Calor, & tota Ventris ſubſtantia, æſtimentur.*

Some there are that will have the Food to be diſſolv'd by a Menſtruum, which is ſupply'd from the Glands of the Stomach, or ſome other way: But thoſe that do ſo far agree in the General, as to think Concoction is perform'd by a Diſſolvent, do differ in their Notions of the Nature of the Menſtruum: For there are ſome that ſuppoſe it to be an Acid, which does erode the groſſer Parts of the Food, and diſſolves them in the ſame manner as Vinegar, Spirit of Vitriol,

Digitized by Google

triol, or any ſuch-like Acid, will diſſolve even ſo ſolid a Body as Iron. And it cannot be deny'd, but that Oil of Vitriol will diſſolve Fleſh-meat, and reduce it to a Pulp; but it is not to be ſuppos'd, that the Fibres of the Stomach can admit any ſuch ſtrong and corroding Acid, without ſomething to correct it, but it muſt be injur'd in its Tone, and labour under great and extraordinary Pains. Neither does ſuch a Menſtruum, tho' it will digeſt ſome things, ſeem capable of diſſolving ſo great a Variety of Things as we eat, eſpecially when a great many of them are of a contrary Nature. Some will have the Menſtruum to be a *nitro-aerius* Spirit, that is, quick, and very penetrating, and included in its proper Vehicle; which, being in its own Nature apt to penetrate the Maſs of the Aliment, does diffuſe it ſelf through the Whole, and breaking the Vinculum of the more ſolid Parts, does diſſolve their Compages. By others, it is thought to be ſome ſaline Juice in the Stomach, by which the Parts of the Aliment are divided and diſſolved, and thoſe which are fit for Nouriſhment, are volatiliz'd.

Laſtly, There are ſome others who reject the Opinions I have already mention'd, and ſuppoſe the Digeſtion of the Food to be perform'd by the Benefit of a Ferment; which, when it is mix'd with the Aliment, excites in the Maſs an inteſtine motion; and the different and contrary motions or tendency of the Parts making ſome kind of Colliſion, gradually break off Particles from the groſſer, and more ſolid Parts, 'till they are ſo attenuated as to be apt to mix more equally with the Fluid, and with them to make one ſoft or chylous Subſtance. But yet there is not amongſt them an univerſal Conſent,

Digitized by Google

sent, either about the Nature of this Ferment, or the manner how it is supply'd. For first, some think it to be the Remains of the Food that was last digested; which having lain some time in the Stomach, after the rest is carried down into the Intestines, contracts an Acid, or some other Quality, and is so alter'd as to partake of the Nature of a Leaven. And this Leaven being a part of the Food, which has been already digested, is so soft and liquid as to be capable of mixing with the Aliment, which is next taken into the Stomach; and being agitated with it by the repeated Pressures of the Diaphragm, Liver, and Abdominal Muscles upon the Stomach in Respiration, does diffuse it self through the whole Mass; and being mixed with it, like Leaven, or Yest added to new Wort, *&c.* puts it into a State of Fermentation; and by this Fermentation, or the Expansion of the Ferment, and the more tenuious Parts, which are first put into motion by it, those which are more solid, and with which they are intermix'd, are rent, and divided, and so attenuated, as to become a soft and pulpous matter. And altho' the greatest part of the Food, that is thus broken and concocted, is by the Contraction of the Fibres of the Stomach press'd into the Duodenum; yet they do not contract themselves so as to force out all the Aliment, but leave between the *Rugæ* or Folds, on the inside of the Stomach, a sufficient Quantity to be a Leaven to the next Meal; and so from time to time.

Some have a Notion, That this Ferment, or Principle of Fermentation, is in the Aliment it self; which being a Congeries of Matter, consisting of various Parts of a different Nature,

is

is no ſooner encloſed in the Stomach, and digeſted in the Heat of that, and the adjacent Parts, but the more ſpirituous and ſubtil Particles are put into motion both from that Warmth, and the difference of their Natures, and enter upon a Fermentation. And ſo by their inteſtine Commotion, and the Violence they offer to thoſe Parts which oppoſe the tendency of any of them, they break and diſſolve what is more ſolid.

Again: Some ſuppoſe, that this Ferment is ſupply'd from the Glands of the Stomach.

And Laſtly, Others, and perhaps with much better Reaſon, contend for the Saliva, and make that to be the Ferment, which ſerves principally for the Digeſtion of the Food; which in Maſtication being mix'd with our Aliment, is with that carried down into the Stomach, where the Parts of it being put into motion by a kindly and agreeable Heat, they do ferment with, and exagitate firſt thoſe Parts of the Food which are moſt apt to ferment with it, and then both conſpire to break and diſſolve the groſſer and more ſtubborn Parts. And *Galen*, in the Book I have before-mentioned, plainly allows that the *Saliva* is concerned in the buſineſs of Concoction, tho' he ſuppoſes the Alteration, which is produc'd by this Juice, to be made in the Mouth, as appears from theſe Words: *Quæ (alteratio) in ore agitur mutat quidem id (nutrimentum) in alteram ſpeciem manifeſte, non tamen ad perfectionem tranſmutat ---- Qui manſi ſunt cibi primum quidem hac Pituita (oris) inbuuntur, & cum ea miſcentur ---- Itaque majorem mutationem conſecuti ſunt, quam ii, qui in vacuis dentium intervallis fuere impacti.*

Now

Now I have given this ſhort Account of the various Opinions of ſome Ingenious Men, concerning the manner how Concoction is perform'd; I come now to propoſe my own Hypotheſis, by which I ſhall endeavour to explain it.

In order to the more eaſie and effectual Digeſtion of the Food, Nature has appointed ſome Parts for the breaking our Aliment, and reducing whatever is groſs into ſmaller Parts, before it is put upon Digeſtion: Others to ſupply the Ferment, by which it is to be diſſolv'd and concocted, and which, before it comes to be included in the Stomach, does moiſten, and make it more ſoft, that it may more eaſily be penetrated and broken by thoſe Parts which ſerve to divide every Morſel into ſmaller Pieces, and prevents the Inconvenience and Trouble which would ariſe from the Nouriſhment ſticking about or between them, when it is dry or viſcous.

For the breaking of that part of our Food, which is not liquid, Nature has furniſh'd us with Teeth, and thoſe of two ſorts: For ſome are ordain'd to divide and break off ſmaller Morſels from a larger Maſs; others are made for the grinding thoſe Morſels into much ſmaller parts. The Teeth, which ſerve to break off Pieces of a convenient Magnitude from a larger Maſs, are of two ſorts accommodated to the Nature of the Subſtance which we eat. Theſe are the *Inciſores*, and the *Dentes Canini*. If the Subſtance, which we have to eat, be not hard, but more eaſily penetrated and divided, then the *Inciſores* are capable of making an Impreſſion upon it, and fix'd firmly enough in the

Jaws

Digitized by Google

Jaws to break off that part which they take hold of. But if it be more ſolid, and not eaſily penetrated, nor any Piece without difficulty to be ſeparated from that Body, whereof it is a part; then we apply the *Dentes Canini*, or Eye-Teeth to it, which are not ſpread, nor have ſuch an edge as the *Inciſores*, but are ſharp and pointed like an Awl, and ſo do more readily penetrate a Subſtance that is hard, and which the *Inciſores* can ſcarcely make any Impreſſion upon. And as the Parts of a more ſolid Body are commonly with more difficulty ſeparated, and there muſt be a greater ſtreſs put upon thoſe Teeth which pull it into pieces; ſo theſe Teeth are much more firmly fixed in the Jaws than the *Inciſores*, tho' they have but one ſingle Root. Beſides, the Poſition of all theſe Teeth is accommodated to their uſe, as being planted oppoſite to the Aperture of the Mouth; ſo that they may be conveniently apply'd to the Subſtance which we have to eat, before it is broken, and when it is too large to be admitted within the Mouth.

The Teeth which do by a Compreſſion and Attrition reduce the little Morſels to ſmaller Parts, are from the manner in which they break the Aliment, called *Dentes Molares*, becauſe they do, like ſo many Mill-ſtones, grind the Food between them. And that they might be render'd fit for this purpoſe, they are made broad at that Extremity, which ſtands out of the Gums, by which means they retain ſome Quantity of the Food between them every time the lower Jaw is pulled up and forc'd againſt the *Maxilla ſuperior*. And as they are broad, ſo they are formed with Inequalities and Protuberances; and by the motion of the lower Jaw,

from

Digitized by Google

from one side towards the other, they grind what they have between them into pieces. The Position of these Teeth too is as convenient as that of the *Incisores*, and the *Dentes Canini*: For being design'd to break those pieces of our solid Food, which are taken into the Mouth, and these pieces, when they are compress'd, and moved by the *Dentes Molares*, being apt to fly out of the Mouth, if there were no Contrivance to prevent it, they are placed beyond the Aperture of the Mouth, and opposite to the Cheeks, which keep the Food within that Cavity, and not only so, but press it in between the *Dentes Molares* on one side, as the Tongue does on the other, until they have sufficiently broken and divided it.

At the same time, whilst the *Dentes Molares* are breaking the Food, there flows into the Mouth a salival Juice which mixes with it, and not only serves to moisten it, and to render it more apt and easie to be divided, but seems to be the Ferment, by the Benefit of which the Food is dissolved and digested. And therefore it is intimately mixed with it, by the Teeth agitating or stirring them together in mastication.

This Liquor, which we commonly call the Saliva, or Spittle, seems to be a Composition made of two several Juices, very different in their Nature: And therefore the several Parts of it are separated by their proper Glands, and Nature has planted no fewer than four pair about the Mouth, which supply the Juices that make the Saliva; to wit, the *Parotides*, and the *Glandulæ Nuckianæ*, the

Digitized by Google

Glandulæ Maxillares internæ, and *Sublinguales*. Whereas if the *Saliva* were but one more ſimple Liquor, a leſs number of Glands might have been ſufficient. At leaſt there appears no Reaſon why one of every Pair ſhould diſembogue it ſelf into the Mouth ſo very near to the Orifice, by which a Gland of ſome other Pair throws in its Juice; and they are not rather all planted at more equal diſtances from one another, ſo to flow in upon every part of the Aliment at the ſame time.

Not that I ſuppoſe, as there are four Pair of ſalivatory Glands, ſo there are four ſorts of Juices ſupply'd from them, to make the *Saliva*; but, as I hinted before, that there are only two different Juices that conſtitute it. And theſe are not only ſufficient, but more proper to excite and ſecure that Fermentation, which is neceſſary to Concoction. For we find that moſt of thoſe Fermentations, which ariſe upon Mixtures made for Experiments, are produced from the mixture of two things; and it is not ſo eaſie to find out three or four ſuch Liquors of a different Nature, as will, upon the mixtion of them all, produce a Fermentation, and from the omiſſion of any one of them diſcover no Diſcord or Diſpoſition to ferment: Beſides, it is certain that two do better ſecure the End, which Nature deſigns. For, if there were three or four different Juices, of which the *Saliva* naturally conſiſts, theſe muſt all have their proper Qualities preſerv'd to them, or elſe the Fermentation, which ſhould ariſe between them, will not neceſſarily follow upon their mixture; and it is certain, that there would be more

Danger,

Digitized by Google

Danger, that one of three or four should be depriv'd of its natural Quality, than one of two.

What Nature these two Juices are of, I do not pretend positively to determine; but so far as I have been able to make my Conjectures about it from Experiments, I do think one of them to be an acid Juice; the other an oleaginous Liquor, something like Oil of Turpentine. For amongst the many Experiments I have made, there was no one that gave me so much Satisfaction, as that which I made with Oil of Turpentine and Oil of Vitriol, tho' I try'd several other things, that will produce a Fermentation upon their Mixture. And it was for this Reason, that I made the Experiment with Oil of Turpentine and the other Oil.

I took a piece of raw Flesh, and having cut it into pices, but much larger than what our more solid Food is reduc'd to by due Mastication, I mix'd some Crums of Bread with it, then I poured in the Oil of Turpentine to them, and upon that the Oil of Vitriol; and having shak'd them together, I digested them about four hours in *Balneo Mariæ*, and then shaking them again in the Glass, I found the Meat dissolv'd, and they all became a thickish Pulp. I could not but take notice, that Oil of Camphire (tho' it does not otherwise seem much different in its Nature from Oil of Turpentine) and Oil of Vitriol, which upon mixture will produce an effervescence as well as the Oil of Turpentine and Oil of Vitriol, yet did not touch the Meat, upon which I poured them, so as in the least to dissolve them. I

Digitized by Google

cannot deny but that an Acid, and a Solution of Salt of Tartar, did dissolve some part of the Flesh-meat, which I mix'd them with, but yet neither so soon nor so perfectly as the two forementioned Oils. And I do the rather think one of those Juices, which constitute the *Saliva*, to be of the Nature of Oil of Turpentine, than of a fix'd Salt, because it will correct and temper even Oil of Vitriol, so as to render it more tolerable to the Fibres of the Stomach. Not that I suppose the acid part of the *Saliva* to come near to the Acidity of Oil of Vitriol. For tho', when they are mix'd, they will make a Liquor that may not be injurious to the Stomach; yet the acid Juice, if it were so corrosive as Oil of Vitriol, would certainly be injurious and painful to the salivatory Ducts, which convey it to the Mouth before it is mix'd with the oleaginous Liquor. But I only say it is an Acid, and in some degree approaches to the Nature of that Oil. And Nature, which can much better adapt several Causes for the Production of such an Effect than Art, may attain her End by a more temperate Acid; tho', at the same time, we may be able to make some probable and true Conjectures about the Nature of those Causes from Experiments.

It being most reasonable to suppose, that there are but two sorts of Juices, of a different Quality, that make the *Saliva*, I do conceive, that four of the eight salivatory Glands, or two pair of the four, do supply one of these Juices, and the other four Glands the other. And this seems to be a very good Reason, why they are so planted, and the Orifice of their Ducts

Digitized by Google

Ducts ſo order'd, that the Juice, which is ſupply'd by one Gland, is diſcharg'd into the Mouth, very near to the Orifice, by which the Juice of a different Nature is tranſmitted from another, ſo that they muſt neceſſarily meet and mix together. Thus the *Glandulæ Nuckianæ*, and *Parotides*, throw in two different Juices by Orifices, which open into the Mouth very near to one another; and the *Glandulæ Maxillares interna*, and *Sublinguales*, do below ſupply the ſame kind of Juices by Orifices, that open ſo near to one another as to ſecure the mixture of the two different Juices.

Theſe Glands, I ſay, do between them afford two divers ſorts of Liquors, of ſuch a Nature as are apt to ferment upon their firſt Mixture, but perhaps more conſiderably when they come to be digeſted by the Heat of the Stomach. So that the Colluctation, or Fermentation, which attenuates and concocts the Food in the Stomach, does not ordinarily ariſe between the Aliment and the *Saliva*, but between the ſeveral Parts of the *Saliva* it ſelf. And indeed, if the *Saliva* did not conſiſt of two Juices, whoſe Nature is in ſuch a manner different, as to render them apt to ferment upon their mixture, it would be very hard to conceive how it ſhould ſo readily and indifferently ſerve for the Digeſtion of all Eatables; how it ſhould ferment with, and diſſolve ſo great a Variety of things, not only of a different, but of a contrary Nature; how it ſhould ferment with Acids as well as Alkalies, digeſt things that are cold as well as hot or temperate; ſome things that are ſalt, others that

Digitized by Google

are insipid, bitter and sweet, mucilaginous, oily, *&c.* But if we suppose, that the Fermentation, which serves for the Digestion of the Food, arises from a peculiar difference in the Nature of two Juices, which constitute the *Saliva*, it will be easie to give a rational Account of our Concoction of innumerable things of a different Nature. And this seems to be as effectual, and a more certain way to attenuate and dissolve the grosser Parts of our Food, than if the Fermentation were made only between the *Saliva* and the Aliment: Besides, the *Saliva* seems to discover a Fermentation upon the mixture of its constituent Juices, even at those times when we do not actually eat; for it is always attended with Bubbles, and a Froth, when it has not been at all agitated in the Mouth, and many of those Bubbles will remain for some considerable time after we have spit it out.

Nature therefore having appointed the *Saliva* for the digestion of the Food, has taken care that it shall be thrown in upon the Aliment on every side. Thus the *Glandulæ Nuckianæ*, and the *Parotides*, supply their Juices to that part of the Food, which lies on the outside of the Gums, between the Cheeks and the Teeth, and the *Glandulæ Maxillares interna*, and *Sublinguales*, do bestow their Liquor upon the Meat, which is within the Teeth and Gums. Neither has she had a Regard only to that Supply, which is due to all the parts of our Food, but likewise to the mixture of the two different Juices of the *Saliva*, which is necessary to its Fermentation. And therefore, as I have already observ'd, the Orifices

Digitized by Google

rifices of the Ducts, which belong to one sort of Glands, are placed near the Aperture of a Duct, which conveys a Juice from one of the other Glands. So the Ducts of the *Glandulæ Nuckiana*, and the *Ductus Stenoniani*, do on each side open into the Mouth, near one another; and the salivatory Ducts of the *Glandulæ Sublinguales*, and the *Maxillares interna*, tho' they have distinct Orifices, empty themselves under the same *Papilla*; and the Juices, which are supply'd by them, meet there, and flow into the Mouth together.

The several Parts of the *Saliva* being discharg'd into the Mouth, in such a manner as to meet and begin a Fermentation, the *Saliva* does, partly as it is agitated with the Food by the Teeth, and some other parts of the Mouth; partly by its own Fluidity insinuate it self into, and mixes with the Food, and not only moistens and softens it, but excites the Fermentation, which is to dissolve it. And when the Aliment is thus mix'd with the *Saliva*, which serves to ferment the whole Mass, it is then to be convey'd into the Stomach, that great digestive Vessel of the Body, where the Fermentation is not only continued but improved.

The Nourishment being convey'd into the Cavity of the Stomach, is there kept for some time in a digestive Heat, all which time it is under a Fermentation produc'd by the different Parts or Juices of the *Saliva*, which are mixed with it; which Fermentation does first agitate the more tenuious or subtil parts of the Food, and puts them into motion, and so with the Fermentation of its own, and those

Digitized by Google

Alimentary Parts, which it firſt communicates a motion to, improv'd by the Heat of the Stomach, the *Saliva* muſt neceſſarily act upon the groſſer Parts. For the inteſtine motion, which is excited in the Maſs, does not give the Particles, which are fermented, the ſame Tendency, but what is ſo various and confus'd, that they muſt inevitably ſtrike not only one againſt another, but againſt thoſe which are more groſs, ſo as to attenuate them, ſometimes by a Colliſion, which ſtrikes off ſmaller Particles from the larger Parts; ſometimes by a Compreſſion, when the Particles which are in motion, happen to ſtrike directly againſt any groſſer Part, on every ſide of it; ſometimes by a kind of Exploſion. For without doubt the *Saliva*, which is fluid, inſinuates it ſelf into the Interſtices of the more craſs Parts of the Aliment, and whatever is agitated and expanded in thoſe Interſtices, requiring a larger ſpace for the Freedom of its motion, and offering a Violence to every thing that oppoſes its Tendency, will, like Gunpowder included in a Shell, force its way out, and tear to pieces that Matter, which does endeavour to confine it.

Thus the groſſer Parts are broken and divided, until they are at laſt ſo far attenuated as to mix more equally with the Fluid, and with them to make one Pulp or Chylous Maſs. And although I do not apprehend how the Stomach ſhould by its reciprocal motions in Inſpiration and Expiration, be able to break and attenuate any Matter, that will not be ſoften'd and diſſolv'd by Agitation in a Liquid; yet it is certain that theſe

Digitized by Google

these motions, caused by the Diaphragm and Abdominal Muscles in Respiration, do make those Parts, which are broken off, as they are dissolv'd, mix intimately with the more liquid; as the Meat which I digested with Oil of Turpentine, and Oil of Vitriol, did by agitation mix more equally with the Oils, and became a Pulpament.

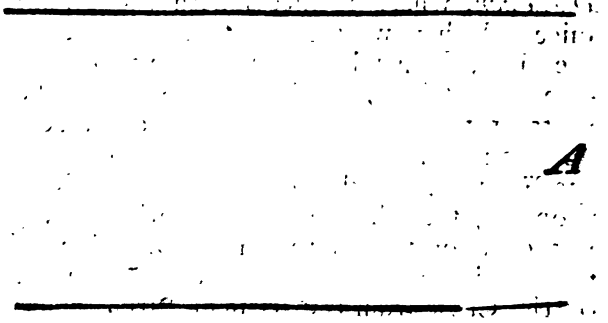
As the Juices, which constitute the *Saliva*, do ferment upon their mixture, so it is probable, that from their Mixture and Fermentation there results such a *Tertium quid*, as is apt to ferment with the Bile. And therefore, when the Aliment has been under the Fermentation, excited by the *Saliva*, a sufficient time, it is then thrown into the *Duodenum*, where it meets with the bilious Juice, which flows into that Intestine from the Liver, from which a new Fermentation seems to begin; and the Commotion of the Parts of the Aliment being still continued, does carry on the Business of Digestion until the Food is perfectly concocted: Tho' it is probable, that this new Fermentation serves not only for the more perfect Digestion of the Food, but likewise for the Separation of the Chyle from the feculent Parts.

Neither do I by a random Guess, and an ungrounded Conjecture, suppose that from the Mixture and Fermentation of the two Juices, which constitute the *Saliva*, there results a Matter, which is apt to ferment with the Bile. But to me the Notion seem'd to be confirm'd by an Experiment that I made. For considering with my self, that the Bile is generally allow'd to have much of a sapo-

nary

Digitized by Google

nary Nature, I made a Solution of Soap in fair Water, and mix'd it with the Oils of Turpentine and Vitriol first put together, and from their Mixture I observ'd a very easie and gentle Fermentation, which continued for a considerable time.



Digitized by Google

A Diſcourſe concerning ſome Influence of Reſpiration *on the* Motion *of the* Heart, *hitherto unobſerved. By* J. Drake, M. D. F. R. S.

THO' divers accurate Treatiſes of the *Heart*, and its Action, have been written by Learned Men of ſeveral Nations, eſpecially by two of our own Country; the Great Dr. *Harvey*, to whoſe happy Sagacity this Nation owes the Glory of the Invention of the *Circulation* of the *Blood*; and the incomparable Dr. *Lower*, to whom we are beholding for a compleat diſplay of the *Mechanical Structure* of the *Heart*, and a moſt ingenious Rationale of its Action. Yet there remain ſeveral doubts and difficulties about it (in my Opinion) not ſufficiently accounted for, towards the reſolving ſome of which, I ſhall offer what my own Thoughts have ſuggeſted to me, and leave it to the Conſideration of the Reader.

The Learned Dr. *Lower* (whoſe accurate Piece on this Argument will inſure his Reputation ſo long as Phyſical Knowledge ſhall laſt in eſteem) has ſo well accounted for the *Syſtole*, or Contraction of the Heart from the *Mechanical* Structure of it, that he ſeems almoſt to have exhauſted the Subject; and had

he

Digitized by Google

he been as happy in diſcovering the true cauſe of the *Diaſtole*, he had left little room for the Induſtry and Sagacity of others about this *Viſcus*.

But having judiciouſly and ſolidly explain'd the *Syſtole*, he contents himſelf to aſcribe the *Diaſtole* to a motion of *Reſtitution*, which Account gives me no ſatisfaction: Becauſe the *Syſtole* being the proper, and (as himſelf confeſſes) the only motion of the Heart, a ſtate of *Contraction* ſeems to be the natural ſtate, and conſequently without external violence, it ſhou'd have no *Diaſtole* at all.

This will appear more plain, if we conſider the Circumſtances of it, and its motion, as a Muſcle, with reſpect to other Muſcles. That Contraction is the proper Action, and State of all Muſcles, is evident from Experience of Fact, as well as Reaſon. For, if any Muſcle be freed from the power of its *Antagoniſt*, it is immediately *contracted*, and is not by any Action of the Will, or Spirits, to be reduced to a ſtate of *Dilatation*. Thus, if the *Muſculi Flexores* of any Joint be divided, the *Extenſores* of that Joint being by that means free'd from the contrary Action of their *Antagoniſts*, that Joint is immediately extended without any conſent of the Will, and in that ſtate it remains; and ſo *Vice verſa*, if the *Extenſores* be divided. From whence it is plain, that the Muſcles have no reſtitutive motion, but what they derive from the Action of their *Antagoniſts* by which they are balanc'd. Thus likewiſe the *Sphincters* of the *Gula*, *Anus* and *Veſica*, having no proper *Antagoniſts*, are always in a ſtate of Contraction, and ſuffer nothing

Digitized by Google

thing to pass 'em, but what is forced thro' 'em by the contrary Action of some stronger Muscles, which, tho' not properly to be called *Antagonists*, yet on all necessary Occasions perform the Office of such.

That the Heart is a Muscle, furnish'd and instructed for motion like other Muscles, is (in my Opinion at least) demonstrated beyond contradiction by Dr. *Lower* and others. And, as it is a *Solitary* Muscle without any proper *Antagonist*, and not directly under the power of the Will, nor exercising *Voluntary* motion, it approaches nearest to the *Sphincter* kind, which only has these Conditions in common with it. But in constant and regular Alternations of Contraction and Dilation, it differs exceedingly from all the Muscles of the Body.

This *reciprocal Æstus* of the Heart has given the Learned abundance of trouble; who, finding nothing peculiar in the Structure, which shou'd necessarily occasion it, nor any *Antagonist*, whose re-action should produce it, have been extreamly perplext to find out the cause of it.

But passing over the various Opinions of Authors, to avoid being tedious, I shall take notice here only of the very Learned Dr. *Lower*'s, in whose Account of the *Systole*, however solid and ingenious, I observe something deficient, and whose *Hypothesis* of the *Diastole* I think to be precarious and false.

This excellent Author, having by sound Arguments drawn from the Structure and Mechanism of the Heart, establisht the Certainty of its *Muscular Motion*, rests satisfied, with-

Digitized by Google

out taking notice of any Assistance, that the Heart receives from any other Part, except from the Brain, by the means of the eighth pair of Nerves.

The Accurate *Borellus*, in his *Oeconomia Animalis*, computes the *Motive* Power of the *Machine* of the Heart to be equal to, or to surmount that of a Weight of 3000 *l.* The *Obstacles* to the motion of the Blood thro' the *Arteries* he esteems equivalent to 180,000 *l.* which is 60 times as much as he rates the Force of the Heart at. Then deducting 45,000 *l.* for the adventitious Help of the *Muscular Elastick Coat* of the *Arteries*, he leaves the Heart with a Force of 3,000 *l.* to overcome a resistance of 135,000 *l.* that is, with 1 to remove 45.

Part. 2d. Prop. 67. Prop. 73.

Prop. 70.

This stupendous Effect he contents himself to ascribe to the *Energy* of *Percussion*. But, had he proceeded in his Calculation to the Veins, which he allows to contain constantly a quantity of Blood, quadruple to the Contents of the Arteries, and to which this *Energy* of *Percussion* does either not reach at all, or but very languidly, he might probably have seen a necessity for some other Expedient to remove so insuperable a difficulty.

But not to insist rigorously on the exactness of this Calculation (tho' the great Abilities of the Author in this way, and his Ingenuity and Modesty, are a sufficient Warrant for the accuracy of his Computations, and the fidelity of his Accounts) we may allow a much greater Deduction, than would be justifiable, without lessening the difficulty. But this account

count I have taken notice of purely for the sake of the Calculation, which may be of use in the Sequel, the account it self being in other respects more defective than Dr. *Lower's*, to which we will return.

The Doctor, notwithstanding his great Sagacity, appears (to me) to have overlook'd something of very great moment, and importance in the explication of the Action of the Heart. For, tho' it should be granted, that the *Muscular Fibres* of the Heart acted by the Nerves, are the immediate Instruments of its *Constriction* or *Systole*; yet it must not be denied, that the *Intercostal* Muscles and *Diaphragm* are of great service to aid and facilitate this Contraction, by opening a Passage for the Blood thro' the Lungs, which denied wou'd be an invincible Obstacle.

Neither do they promote it that way only. The manner how they farther assist the Heart in its Contraction, will appear manifestly, if we consider the different Posture, Situation, and Capacity of the Blood-Vessels of the Lungs in the several times of *Elevation* and *Depression* of the *Costæ*.

The *Pulmonary* Artery rises from the *right* Ventricle of the Heart, and runs in one Trunk, 'till it comes to the *Aspera Arteria*, where it is divided, and sends a Branch along with each Division of the *Aspera Arteria*, according to all the minutest Subdivisions, of which it is likewise subdivided, accompanying all the *Bronchi*, in their whole progress through the Lungs.

The *Pulmonary* Vein, which empties it self into the *Left* Ventricle of the Heart, spreads it

it self on the *Aspera Arteria* and *Bronthi*, in the same manner that the Artery does.

The necessary consequence of this Disposition is, that this Artery and Vein being co-extended with, and fasten'd to the *Bronchi*, must needs suffer such alteration of *Superficial* Dimensions, as the *Bronchi* do in the *Elevation* or *Depression* of the *Costæ*.

While the Ribs are in a state of *Depression* (whether before Commerce with the external Air or after) the *Annular Cartilages* of the *Bronchi* shrink one into another, and by that means their *Dimensions* are exceedingly contracted. In conformity to this condition of the *Bronchi*, the *Pulmonary* Artery and Vein must likewise, either by means of their *Muscular* Coats contract themselves to the same *Dimensions*, or lye in *Folds* or *Corrugations*, which is less probable.

On the other hand, when the Ribs are elevated, and the *Diaphragm* bears downward, the Air rushing into the Lungs, shoots out the *Cartilaginous* Rings, and *divaricates* the Branches of the *Trachea*, and by them extends and divaricates the several Divisions of the *Pulmonary* Artery and Veins, and thereby lengthens and enlarges their Cavities.

This enlargement of their Cavities is very considerable, not only upon the score of the addition, which they receive in length thereby, but also upon the account of their *Divarication*. For whereas, when the Ribs are depress, and the Lungs subside, the Blood-Vessels are not only contracted, (as I have already observ'd) but their Branches, which are exceeding numerous, approach one another,

and

Digitized by Google

and lie in juxta-position, by which their Cavities are very much compress'd and streightned: When the Ribs are elevated, and the Lungs turgid with Air, not only the Fibres, by which their Coats in the opposite state were contracted, are extended; but those innumerable Vessels, which lying before in lines almost parallel upon one another, compress'd one another, making an *acute* Angle at their Junctures, are divaricated and separated from each other, and make an *obtuse*, whereby their Chanels are widen'd.

Thus a passage is open'd to the Blood, from the *Right* Ventricle of the Heart to the *Left*, thro' the Lungs, to which it cou'd not otherwise pass; and the opposition, which the Blood contain'd in that Ventricle, must otherwise necessarily have made to its Constriction, is taken off, and the *Systole* thereby facilitated.

Nor is that all. For the *Diastole* being caus'd (as I shall in the Sequel shew) by the force of the Blood rushing into the Ventricles, this Ampliation aad Extension of the *Pulmonary* Artery is a sort of *Check* or *Counterpoise* to it, and prevents an endeavour towards two contrary Actions at once, which must necessarily frustrate both. For the Heart being a *Springy*, *Compressible* Body, whose proper Action, which is Contraction, depends on the influx of certain Fluids into its Fibres, or Substance; and containing besides a Fluid in its *Ventricles*, or great Cavities, in one of which is the Mouth of this Artery, the action of this Vessel must in great measure resemble that of a *Syringe*, whose extremity is immers'd in Wa-

Digitized by Google

ter, the Enlargement or Expansion of the Chanels of the Artery answering the drawing of the *Embolum*, as the constrictive motion of the Muscle of the Heart does the pressure of the *Atmosphere* upon the *Surface* of the Water, the one making way for the fluid, and the other forcing it to follow, where the resistance is least. In this sense we may allow a sort of Attraction to the *Pulmonary*-Artery, depending wholly upon the Action of the *Intercostal* Muscles and *Diaphragm*, which we must therefore confess to be very serviceable and instrumental in promoting the *Systole* of the Heart.

But if the Learned Author be deficient in his account of the *Systole*; that is, if he has not observ'd all the Mechanism and Contrivance of Nature for the Contraction of the Heart; much less sufficiently has he accounted for the *Diastole*, or Dilatation of it, which he ascribes to a motion of *Restitution* of the over-strain'd Fibres, which yet he confesses are made for *Constriction* only. 'Tis true, he immediately after joins the *Influx* of the *Blood* as a concurrent cause; but from the slight notice that he takes of it, 'tis plain, that he did not so much as dream of any great share it had in that action. His words are these:

De Corde, Pag. 75. *Quin & (ut obiter hoc moneam) cum omnis motus contractione perficiatur, & Cordis Fibræ ad constrictionem solum factæ sint, apparet quoque Cordis motum* totum *in* Systole *positum esse; cumq; Fibræ ultra tonum suum in omni constrictione ejus tendantur, idcirco ubi nixus iste absolvitur, motu quasi* restitutionis *Cor iterum relaxatur, & sanguine*

guine a Venis influente *rursus distenditur*; *a* nullo *enim cordis motu, nisi* tensionem suam remittente, *& ab* irruente *sanguine* Diastole *ejus librat is adeo viribus succedit.*

I have transcribed the intire Paragraph, because it contains his whole *Hypothesis* of the *Diastole*, and all the notice that he takes of it thro' his whole Work. But how slender soever this may prove, it is the most substantial that I have any where met with, except a late one of Mr. *Cowper*, which is properly an Improvement of this, and shall be considered in the Sequel.

But, if Contraction be the sole Action of these Fibres (as this Great Man confesses it to be) and as indeed it is of all *Muscular* Fibres, I wonder how so judicious a Writer came to slip into such an absurdity, as to call their Distention (vulgarly but improperly called Relaxation) a Motion of *Restitution*. For from the Nature of those Fibres, and their disposition in the Structure of the Heart, the natural State of the Heart appears manifestly to be *Tonical*, and its Dilatation a State of Violence; and consequently, the Constriction is the *true* motion of *Restitution*, and the State to which it will *spontaneously* return, when the Force is taken off, which is the work of the *Intercostal* Muscles and *Diaphragm*.

Thus we are left still to seek for the true cause of the *Diastole*, which seems to me to be the main and most difficult *Phænomenon*, relating to the Heart and the Circulation of the Blood. But in Mr. *Cowper*'s ingenious *Introduction* to his *Anatomy of Humane Bodies*, I

Digitized by Google

find the Share which Dr. *Lower* hints the Blood to have in that Action, further prosecuted, and improv'd into the main Instrument of the Dilatation of the Heart, wherein I agree intirely with him. But as to the manner, and reasons of its being so very instrumental, I can't be so perfectly of his mind.

The Heart (says this accurate Anatomist) *of an Animal bears a great Analogy to the Pendulums of those Artificial Automata, Clocks and Watches, whilst its motion is performed like that of other Muscles, the Blood doing the Office of a* Pondus.

This Explication, being but a Simile without a distinct application to Particulars, is beside so very short, that I can at best but give a conjecture at the meaning, which if I mistake, I shall deserve to be excused, and expect to be better inform'd.

By the *Blood*'s doing the Office of a *Pondus*, I suppose he means, that the Blood contributes in the same manner to the motion of the Heart, as the *Weights* do to that of the *Pendulum* of a *Clock*. If so, the Blood, according to him, must be the Instrument of *Constriction*; and *Dilatation* mast be the *Natural* State, or *Spontaneous* Motion, to which it wou'd, when under no violence, return; the contrary of which, I presume, will appear ere I have done.

But if he means, that the *Blood* in its reflux, by *gravitating* on the *Auricles* and *Ventricles*, dilates and expands 'em, acting therein as a *Counterpoise* to its contractions as a Muscle, I cou'd wish his Design had not bound him up

to

Digitized by Google

to ſo narrow a compaſs, and that he had given us an explication at large of ſo abſtruſe and ſo important a *Phænomenon*: Becauſe the *Specifick Gravity* of the Blood ſeems to me a cauſe by no means alone adequate to the effect, which it is here ſuppos'd to produce.

For, if the Blood acts only as a *weight* by meer *gravitation*, then that part of it only which deſcends from the Parts above the Heart can be employ'd in that Action. This at the largeſt computation can't amount to Five pound weight, and muſt, according to the computation of *Borellus*, force a Machine, that is able to overcome a reſiſtance of 135,000 *l.* I leave every man to deduct what he ſhall upon examination find reaſonably to be deducted, and yet ſhall reſt ſecure, that it is not to be effected in the leaſt with ſo ſmall a Weight.

But neither does the *Reſluent* Blood gravitate in any ſuch proportion, as I have here aſſign'd. For to make a true eſtimate of its *Gravitation*, we muſt conſider the Circumſtances of the Liquor ſuppos'd to gravitate; in which it very much reſembles Water inclos'd in a recurve Tube, of which, if the length of the two Legs be equal, it may be ſuſpended in the Air full of Water, with the Extremities downwards, without loſing a drop, altho' the *Diameter* of thoſe Legs ſhou'd be very unequal. The Caſe of the Arteries and Veins is pretty near a parallel to a Tube, ſo fill'd and inverted. For, if the Arteries and Veins be continued Tubes, (as by the Microſcope they are made to appear) then ſuppoſing their contents to have no other deter-

Digitized by Google

mination of motion, than their own weight wou'd give them, the contain'd Fluids must be counterpoises to each other. For the Veins and Arteries being join'd at the smaller Extremeties, and the larger of both terminating in the same parallel Line, it is impossible, according to the Laws of *Hydrostaticks*, that the contents of either shou'd overbalance t'other. How far then must it fall short of forcing the natural Power and Resistance of so strong a Muscle as the Heart, by meer Gravitation.

The Blood indeed has a *Progressive* Motion thro' its Vessels, wherein it differs from Water, in a recurve Tube, in the Experiment above-stated. But, if the natural Gravitation of the Blood contributes nothing to the Dilatation of the Heart, this progressive motion will not be found much more sufficient. For, as this motion is deriv'd intirely from the Heart's Constriction (as all accounts hitherto derive it) cou'd the Blood be suppos'd to re-act upon the Heart, with all the force first impress'd upon it by the Heart, it wou'd be insufficient, unless we will suppose the *Force communicated* to be superiour to the *Power Communicant*, which is absurd.

But when the just and necessary Deductions for the Impediments, which the Blood meets with in its Progress thro' the Vessels shall be made, the remaining Force will be found so inexceeding weak, that to prop the Blood thro' the Veins may be a task alone too great for so small a Power, without charging it with the additional difficulty of forcing the Muscle of the Heart.

Alphonsus

Digitized by Google

Alphonsus Borellus, after a great deal of solemn pains taken to shew his care and exactness, and to possess his Reader of the truth of his Calculations, casts up the force of the Heart, and the *Muscular* Coat of the Arteries, to be together equal to a weight of 3,750 *l.* and allots 'em a Resistance equal to 180,000 *l.* to overcome which is 45 to 1. To make up for a disproportion, by his own confession, incredible to those who have not considered the matter as he had done, he flings into the Scale the additional *Force of Percussion*, which he leaves *indefinite*, and thinks sufficient to *force any quiescent finite Resistance whatsoever*.

But as this Account and *Hypothesis* are part of a Posthumous Work (if a liberty of Conjecture may be allow'd in so uncertain a matter,) I shou'd suspect, that these Papers were left unfinish'd by *Borellus*; or at least, that in many places the last hand was never put to 'em. For neither in this Place, nor any other of this Work, does he account for any more than the *Systole* of the Heart, and the resistance which is made to the progressive motion of the Blood in the Arteries only. This alone he found to exceed the Power of the Heart so prodigiously, that he seems to shuffle it off his Hands with a general and precarious Solution, as a difficulty that he was desirous to be rid of. For, having ascrib'd this *stupendous* (as he himself calls it) effect to the *Energy of Percussion*, he takes no care to satisfie his Reader any farther about it, or to refer him, or give him the expectation of satisfaction any where else; altho' he has an express Treatise on the *Force of Percussion*, which was written

Digitized by Google

preparatory to this, and to which he frequently refers in other Places of this Work. But what confirms my suspicion, that this part was intended for a farther Revise by the Author, is, that he has left the Progress of the Blood thro' the Veins, and the *Diastole* of the Heart, absolutely untouch'd, tho' they are difficulties of a much greater magnitude than this, which he has attempted to account so slightly for: For, in these he is excluded the benefit of *Percussion*, and has yet a greater resistance to overcome without it. Omissions of this kind are so unusual with this Author, where-ever he knows himself to go upon sure grounds, that it is to me an Argument, that he doubted the sufficience of his *Percussion*, and reserv'd these important *Phænomena* for farther consideration, without plunging himself into such an Absurdity, as to ascribe to *Percussion* any such *Energy* as to be able (so broken as it returns to the Heart) by its re-action to force that Power, from whence only it was at first deriv'd.

Dr. *Lower*, and Mr. *Cowper*, deliver their Opinions of the Cause of the Dilatation of the Heart so very short, and without any Arguments to support 'em, that by exposing 'em naked, they seem rather to discourse of it transiently, as men obliged by the nature of their Subjects to say something of it, than solicitous to give any full or satisfactory Account; and therefore I shall proceed no farther upon 'em here.

But tho' the *Hypothesis* of *Borellus* may, in this case, be found precarious or insufficient (a misfortune that has befallen him in divers other

other Particulars) his *Theory* holds still good. At least it ought to be allowed, in justice to his great Abilities and Exactness, 'till some body convicts him of some material Error in his Calculations, which has not as yet been done by any body, that I know of.

Supposing then the force of the Heart, and of the *Muscular* Coat of the Arteries, as likewise of the resistance, which they must overcome, to be computed with any degree of accuracy, there remains yet such a prodigious disproportion to be accounted for, as requires some more powerful Agent, than any yet assign'd, to make up the deficiency.

What assistance the Heart receives from the action of the *Thorax* towards the facilitating its contraction, without which assistance there cou'd have been no *Systole*, has been already shewn. But neither the *Intercostal* Muscles, or *Diaphragm*, which are so instrumental in that part of its action, can contribute any thing to the *Diastole*; because they serve only to enlarge the cavity of the *Thorax*, and thereby to open a passage to the Blood from the Heart, and promote its Constriction.

Whatever therefore the force is, that dilates the Heart, and is the cause of the *Diastole*, it must be equal to that of the Heart, the *Intercostal* Muscles and *Diaphragm*, to all which it acts as an Antagonist. I take no notice of the *Serratus Major Anticus*, and other Muscles; which have an obscure share in the *Elevation* of the *Costæ*, because as much may reasonably be deducted upon the account of the *Obliquus externus Abdominis*, and other Muscles; which having their Insertions on some of the lower *Ribs*, are as Instrumental

towards

towards the *Depression* of 'em, and so balance the Account. But the chief use of these is in violent Respiration: In ordinary Respiration their share is small.

Such a real Power (which may in the least be suspected of any share in this Action) is hard, perhaps impossible to be found in the *Machine* of any *Animal* Body; and yet without some such Antagonist, it is as impossible the Circulation of the Blood shou'd be maintain'd. All the Engines yet discover'd within the Body, conspire towards the *Constriction* of the Heart, which is the *State* of *Quiescence*, to which it naturally tends. Yet we find it alternately in a *State* of *Violence*, that is, of *Dilatation*; and this upon necessity, because upon this *Alternation* depends all Animal Life.

Some sufficient Cause external must therefore be found, to produce this great *Phænomenon*; which Cause must be either in the *Air*, or *Atmosphere*, because we have no constant and immediate Commerce with any other *Medium*.

Some great Physicians observing this, and that depriv'd by whatsoever means of Communication with the *external* Air, we became instantly extinct, have imagin'd, that in the Act of Inspiration certain purer parts of the Air mixed with the Blood in the Lungs, and was convey'd with it to the Heart, where it nourish'd a sort of *Vital Flame*, which was the cause of this reciprocal *Æstus* of the Heart. Others not quite so gross, rejecting an *Actual Flame*, have fancied that these fine Parts of Air mixing with the Blood in the Ventricles of the Heart, produc'd an *Effervescence*, which dilated it. But these Fancies have been long

since

Digitized by Google

since exploded and condemn'd upon ample Conviction; and 'tis a Point yet undetermin'd, whether any Air does mix with the Blood at all in the Lungs, or not.

But supposing, that some Air may insinuate it self into the *Pulmonary* Vein, it can no other way dilate the Heart than by an Effervescence in the Left Ventricle, which wou'd not dilate the Right. But this Opinion is contradicted by *Autopsie*, and too laboriously confuted by others, to be brought upon the Stage again here.

There remains therefore only the *gross Body* of the *Atmosphere* to be considered, which is undoubtedly the *true Antagonist* to all those Muscles, which serve for ordinary Inspiration, and the Constriction of the Heart. This will appear more evidently, if we consider not only the power, but the necessity of its Action upon *Animal* Bodies, as well as the want of other sufficient Agents.

The Heart is a *Solitary* Muscle of very great strength, and the *Intercostal* Muscles and Diaphragm, which likewise have no *Antagonists*, are a vast additional Force, which must be balanc'd by the contrary Action of some equivalent Power or other. For, tho' the Action of the *Intercostal* Muscles be voluntary, that does not exempt 'em from the condition of all other Muscles serving for *voluntary* motion, which wou'd be in a State of perpetual Contraction, notwithstanding any Influence of the Will, were it not for the libration of *Antagonist* Muscles. This libration between other Muscles, is answer'd by the *Weight* of the incumbent *Atmosphere*, which presses upon the *Thorax* and other parts of the Body. And,

as

Digitized by Google

as in all other voluntary motions the influence of the Will only gives a prevalence to one of it two Powers before equilibrated, so here it serves to enable those Muscles to lift up a weight too ponderous for their strength not so assisted; and therefore as soon as that assistance is withdrawn, the *Costæ* are again depress'd by the meer *Gravitation* of the *Atmosphere*, which wou'd otherwise remain elevated thro' the natural Tendency of those Muscles to contraction.

This is evidently prov'd from the *Torricellian* Experiments, and those made upon Animals in Mr. *Boyle*'s Engine; where, as soon as the Air is withdrawn, and the *pressure* thereby taken off, the Intercostal Muscles and Diaphragm are contracted, and the Ribs elevated in an instant, and can't by any power of the Will be made to subside, 'till the Air is again let in to bear 'em forcibly down.

It were scarce worth while to take notice here of a Mistake of the Learned Dr. *Willis*, were it not for the great Authority of the Man, which is almost sufficient to keep Error in countenace. The Doctor having observ'd, that the Fibres of the *External* and *Internal Intercostal* Muscles ran in a contrary order, as it were, decussating each other, takes occasion from thence to fansie, that there was an opposition in their Office; and that as the *External* serv'd to raise up the Ribs, the *Internal* drew 'em down again, forgetting at that time, That, when a contractile Body is fasten'd at the several ends to Points unequally moveable, let the Contraction happen in what part or manner soever

De Respirationis Organis & Usu.

Digitized by Google

ver, the more moveable Point must be drawn towards the less moveable: By which Rule, whether *External* or *Internal Intercostals* be contracted, the lower Ribs will be forc'd to approach the upper, that is, be rais'd up.

As in the Elevation of the *Costæ*, the Blood, by the passage that is open'd for it, is in a manner solicited into the Lungs,; so in the Depression of 'em, by the subsidence of the Lungs, and the contraction of the Blood-Vessels, both which are consequent thereof, the Blood is forcibly driven, as it were with an *Embolum*, thro' the Pulmonary Vein into the Left Ventricle of the Heart. And this, together with the *general Compression* of the *Body* by the *weight* of the *Atmosphere*, which surrounds and presses upon the whole Surface of it, is that Power which causes the Blood to mount in the Veins, after the force impress'd upon it by the Heart is broken and spent, and which is sufficient to force the Heart from its natural State to Dilatation.

He that is able to compute the weight of a Column of Air, equal to the Surface of the whole Body, will readily grant it a power sufficient for the Effects, which are here ascrib'd to it. And when he considers, that the Bodies of Animals are compressible Machines, he will find that it must of necessity affect them in the manner here laid down. But tho' our Bodies be entirely compos'd of *Tubuli*, or Vessels fill'd with Fluids; yet this pressure, how great soever, being equal, cou'd have no effect upon 'em, if the superficial Dimensions were not easily variable; because being compress'd on all parts with the same degree of Force, the contain'd Fluids cou'd not any where

Digitized by Google

where begin to recede, and make way for the rest to follow, but wou'd remain as fix'd and immoveable as if they were actually solid. But by the Dilatation of the *Thorax*, room is made for the Fluids to move, and by the Coarctation of it fresh motion is impress't, which is the main Spring whereby the Circulation is set and kept going.

This reciprocal Dilatation and Contraction of the superficial Dimensions of the Body, seems so necessary to Animal Life, that there is not any Animal so imperfect as to want it, at least none to the inward Structure, of which our Anatomical Discoveries have yet reach'd. For, tho' most kinds of *Fish* and *Insects*, wants both *moveable* Ribs and Lungs, and consequently have no dilatable *Thorax*, yet that want is made up to 'em by an *Analogous* Mechanism, answering sufficiently the Necessities of their Life.

Those Fishes which have no Lungs, have *Gills*, which do the *Office* of Lungs, receiving and expelling alternately the Water, whereby the *Blood-Vessels* suffer the same alteration of Dimensions, that they do in the Lungs of more perfect Animals.

The Lungs or *Air-Vessels* of Insects, are yet exceedingly more different in Structure, Distribution, and Situation from those of perfect Animals, than those of Fishes are, and yet in their Use and Action agree perfectly with both; that is, *receiving* and *expelling* the Air, and *varying* the *Dimensions* and *Capacities* of the *Blood-Vessels*. These having no *Thorax*, or separate Cavity for the Heart and Air-Vessels, have the latter distributed thro' the whole Trunk of their Bodies, by which they communicate

Digitized by Google

communicate with the *External* Air through ſeveral *Spiracula* or *Vent-holes*, to which are faſten'd ſo many little *Trachea*, or Wind-pipes, which thence ſend their Branches to all the Muſcles and *Viſcera*, and ſeem to accompany the Blood-Veſſels all over the Body, as they do in the Lungs only of perfect Animals. By this diſpoſition in every *Inſpiration*, the whole Body of theſe little Animals is inflated, and in every *Expiration* compreſs'd; and conſequently the Blood-Veſſels muſt ſuffer a *Viciſſitude* of Extenſion and Contraction, and a greater motion muſt thereby be impreſs'd upon the Fluids contain'd in 'em, than the Heart, which does not in thoſe Creatures appear to be Muſcular, ſeems capable of giving.

The only Animal that is exempted from this neceſſary condition of *Breathing*, or *receiving* and *expelling alternately ſome Fluid* into and out of the Body, is a *Fœtus*. But this, while included in the Womb, has little more than a *vegetative* Life, and ought ſcarce to be reckon'd among the number of *Animals*. For, were it not for that ſmall ſhare of *Muſcular* Motion, which it exerciſes in the Womb, it might without abſurdity be accounted for as a Graft upon, or Branch of the Mother.

Concerning the immediate matter, and means of Life, and Nutrition, Authors are not agreed, nor is it the buſineſs of this place to reconcile, or decide their differences, but to account for the motion of the Blood thro' the Veſſels only. In order to this, it will be neceſſary to obſerve, that the Pulſation of the Heart in a *Fœtus* is ſo very weak and obſcure, and the motion of the Blood ſo extream ſlow

and

Digitized by Google

and languid, as to be scarce, if at all, perceivable, as has been experienced in the Dissection of Puppies before Respiration had. To produce such a feeble Palpitation, and creeping Motion, no greater force seems to be required, than may be deriv'd from the Communication between the Vessels of the Mother and *Fœtus* in the *Placenta*. I am not ignorant, that divers very Learned Anatomists (whom the Crowd have implicitly follow'd) have absolutely rejected all Communication between these Vessels. But, with submission to Great Authorities, I think they have acted arbitrarily, and without sufficient Warrant from Reason or Experiment: For neither are the Arguments which they bring against it conclusive, nor the Office which they assign to the Umbilical Vessels in lieu of it, proper, or natural to those Vessels, or the reality of the Fact made out by any substantial Reasons. Those that reject this Communication usually do it in favour of one or both of these Opinions, that the Arteries of the *Uterus* do deposite a Nutritive Juice, or a Juice impregnate *with Air* in the *Placenta*, which is suck'd in by the *Umbilical* Vein, and convey'd to the *Fœtus*, for the necessary Uses of Nutrition and Life. Now those that patronize either of these Opinions, lead Nature an unnecessary Dance. For if the *Maternal* Blood does really contain any such *Nutritious*, or any such necessary *Aerial Particles*, why shou'd they be separated and extravasated, to be with difficulty receiv'd into the *Umbilical* Vein, and again

Boyle *of the Elasticity of Air.* *Pechlinus de Aeris & alimenti defectu.*

Digitized by Google

gain mixt with the Blood, when they might more eaſily have been imparted by the plain ſimple way of Transfuſion from the Arteries of the *Mother* to the Veins of the *Fœtus*. And, that this is the courſe which Nature takes in this caſe, I am perſwaded from the eaſineſs and ſimplicity of the Method, which readily performs what might be perhaps in vain expected from t'other, and wou'd over and above find 'em, what they ſeem to grope ſo blindly about for, a firſt Mover of the Blood in a *Fœtus*.

Thoſe that contend for the conveyance of the *Nutricious* Juice, thro' the *Umbilical* Vein from the *Placenta*, are forced upon two difficulties next to Abſurdities. For firſt, they are oblig'd to make this Vein, which, as all other Veins, ſeems dedicated to the re-conveyance of Blood only, the proper and immediate Chanel, thro' which a very different Liquor is to be carried; and next, to give a Power of Attraction or Suction to it; becauſe the *Nutricious* Juice, which it is thus deſtin'd to carry, is both viſcous and ſtagnant, and has neither force to drive, nor ſubtilty to penetrate, or inſinuate it ſelf into the Capillary Veins; and therefore muſt be drawn or ſuckt as *Milk* is from the *Breaſt*, to which the *Placenta* and its *Nutricious* Juice are by the Favourers of 'em expreſly compared. But if this were the ſole uſe of the *Placenta*, and *Umbilical Veſſels*, why were the Umbilical *Arteries* ſent along with the Vein? Their buſineſs is not to bring any thing back to the *Fœtus*, nor can they contribute any thing to the benefit of the *Mother*; for the *Uterine* Arteries bring

Digitized by Google

all to the *Placenta*, the Umbilical Vein carries it to the *Fœtus*, and the *Uterine* Veins convey back again the Surcharge of the *Mother's* Blood; the Umbilical *Arteries* only, have nothing to do, and are superfluous and impertinent, which is contrary to the constant practice of Nature. Yet if *Autopsie* did in the least countenance this Hypothesis, some defence might still be made; but we find in the Umbilical *Vein* of a *Fœtus* nothing but *Florid* Blood, such as in all probability it received immediately from the *Arteries* of the *Mother* without any mixture. And therefore I can't help concluding, that this Opinion engages its Favourers in some Absurdity, without Necessity and without Proof.

They that from the *Placenta* supply the Body of the *Fœtus* with *Air*, are as much distress'd as t'other; for they are forc'd to beg the Question twice, which, even when granted, will not answer their ends. First, they suppose, that an intimate mixture or confusion of *Air* with the *Blood*, is necessary for the support of Animal Life, a *Postulatum*, which perhaps the former part of this Discourse may have render'd unnecessary; and next that, the *Fœtus* is supply'd with *Air* from, and its *Blood* mixt with it in the *Placenta*.

But here again they fetch a Compass without necessity or proof. For if a mixture of *Air* were necessary to a *Fœtus*, why should it be separated from the *Mother's* Blood, and not rather both communicated together, since it is so much more easie and commodious. But neither does the *Placenta* seem to be instructed

Digitized by Google

ſtructed and provided for the ſeparation of *Air*, but of a much *groſſer Fluid*, deſtin'd to ſome other uſe, which *Autopſie* confirms: Yet, were both theſe Opinions true, they are however defective, and the Circular Motion of the Blood unprovided for.

By the way of *Transfuſion*, this great Phænomenon is naturally accounted for, and the ends, for which the other two Hypotheſes were divis'd, might both be anſwered with more eaſe. For the *Hyſterick* Arteries tranſmitting their Blood immediately to the *Umbilical* Vein, may very eaſily tranſmit ſuch *Nutricious* Juices or *Aerial* Particles, as are contain'd in the Blood along with it, without depoſiting 'em by the way. By this means ſo much of the Impulſe of the Mother's Blood is preſerv'd, as ſuffices to maintain that languid Circulation which a *Fœtus* enjoys. For the Blood being driven thro' the *Arteries* of the *Uterus* into the *Umbilical Vein*, is convey'd directly to the *Sinus* of the *Porta*, and thence by a ſhort and direct paſſage thro' the *Cava* to the Heart; where paſſing thro' the *Foramen Ovale* to the *Left* Ventricle, and thro' the *Canalis Arterioſus* from the *Right* and *Pulmonary* Artery, it is all deliver'd without coming at the *Lungs* to the *Aorta*, and from thence again by the *Umbilical Arteries* to the *Veins* of the *Uterus*, making a ſort of *Epicycle* to the main Circulation in the Mother.

As this Opinion is favour'd by the ſtructure and diſpoſition of the Blood-Veſſels on both parts, ſo there is nothing in it difficult to be conceiv'd, or repugnant to experience. Late Diſcoveries have made it appear, that the Ar-

Digitized by Google

teries and Veins are continued Tubes, and that the latter contain nothing but what they receive from the former, and no reaſon appears why we ſhou'd think this Method to be varied in the *Placenta*. On the other hand, if the Arteries of the *Uterus* were continued to the Veins of the *ſame* part, and thoſe of the *Fœtus* in like manner, without communicating with each other, their confluence in the *Placenta* ſeems to be altogether impertinent, and of no uſe, and the *Umbilical* Arteries and Vein fram'd for no other ſervice or purpoſe, than to give the Blood room for an idle Sally.

Thus the reaſonableneſs of this old Opinion may be vindicated, but the certainty of it reſts upon ſtronger proof. Mr. *Cowper*, to whoſe happy Induſtry we owe the Confirmation of many ancient Diſcoveries, and the benefit of ſome new ones, has the honour to re-eſtabliſh this old, but long exploded Truth. For by pouring *Mercury* into a Branch of the *Uterine Artery* of a *Cow*, that went into one of the *Cotyledones* of the *Uterus*, he fill'd thoſe Branches of the *Umbilical* Veins, which went from that *Cotyledon* to the *Navel* of the *Fœtus*; which, with a part of the *Uterus*, he keeps prepared by him.

It wou'd be a weak Objection, to alledge, that the Obſervation and Experiment being made on the *Uterus* of a *Cow*, the Inference wou'd not hold from thence to a *Woman*, the one being *Glanduliferous*, and the other *Placentiferous*; ſince ev'ry one of theſe *Cotyledones*, or *Uterine Glandules*, is in all reſpects a little *Placenta*, and all the difference between 'em is in number, name, and magnitude. Why *Ruminants*

Digitized by Google

minants differ in this Particular from other *Viviparous* Animals, is beſide the Subject of our preſent Enquiry. But the great Flux of Blood, which conſtantly follows upon drawing the *Placenta* from Women (which is frequently ſo great as to coſt 'em their Lives) is as plain a demonſtration to Reaſon of the *Continuity* of the Veſſels, as Mr. *Cowper*'s Experiment is to the Eye.

I have heard it objected by very learned Men, that if there were ſuch a *Continuity* of Veſſels, and ſuch *Tranſfuſion* of Blood, the *Fœtus* muſt neceſſarily periſh thro' loſs of Blood, upon the ſeparation of the *Placenta* from the *Uterus*; but that, on the contrary, no viſible flux of Blood does follow while the *Fœtus* continues wrapt in the Membrane, in which condition it may be kept alive ſome hours. To this it may be anſwer'd, that the Circulation in the *Fœtus*, being deriv'd from the Mother, may be ſuppos'd wholly to ceaſe upon the cutting off the Communication between 'em, 'till it is again renew'd more forcibly by *Reſpiration*. But if we allow the motion already impreſs'd upon the Blood to be ſufficient to keep it going a little while; yet it muſt needs be ſo exceeding languid, that the meer reſiſtance of the external Air muſt be more than enough to hinder any Efflux of Blood from a *Fœtus* before Reſpiration. How long Life may be preſerv'd without an *actual* Circulation of the Blood, is a queſtion not of this place. But we have been convinc'd by many and notorious Obſervations and Experiments, that Life has been recover'd a long time after all tokens of Reſpiration, Circula-

Digitized by Google

tion, or even Life it ſelf have diſappear'd, ſo that we can't think the firſt Solution either impoſſible or improbable.

I expect to be told, that in the early days of *Geſtation* in *Viviparous* Animals there is no *Placenta*, or any Adheſion of the *Umbilical* Veſſels to any part of the *Mother*, and conſequently no ſuch *Transfuſion*; and that in *Oviparous* there is no *continuity*, or *communication* of Veſſels of any kind, during the whole time of *Incubation*.

But theſe Objections carry neither the weight nor difficulty along with 'em, that they may be ſuppos'd to do; for in thoſe days there is neither *Blood* nor *Blood-Veſſels*, and conſequently there can be no *Circulation* of the Blood; and the *Embryo*, of what Species ſoever, is no more than a *Vegetable* at that time; nor does the *Fœtus* of any *Viviparous* Creature enjoy any *Circulation*, or ſhew any ſigns of Animal Life, 'till after thoſe Veſſels, as well as others requiſite to the Circulation, are compleated.

It muſt be confeſs'd, that *Oviparous* Animals are denied the Benefit of this Communication; but that want is ſufficiently compenſated by a peculiar Mechaniſm, which directly anſwers the ends of *Reſpiration*, and the *preſſure* of the *Atmoſphere* upon the *Fœtus*. There is at the *obtuſe* end of an Egg a ſmall Cavity fill'd with Air, which is the ſuccedaneous Inſtrument to the *Reſpiratory* Organs. For as ſoon as the Contents begin to be warm'd by the *Incubation* of the Hen, or *any analogous* Heat of *Furnace* or *Dunghil*, the ſeveral Humors of the Egg require a *fermentative* motion,

Digitized by Google

tion, and the *Air* contain'd in the *Cavity* or *Vesicle*, at the *obtuse* end of the Egg is rarefied, and the Vesicle extended and enlarg'd, and consequently the other Contents are compress; to which the *fermentative* motion naturally resists. But both Bodies being as well *compressible* as *dilatable*, and both having an *expansive* motion impress upon 'em by *Incubation*, the compression and renitency will be mutual, but varied in degree, according as either, thro' the variation of Circumstances, shall prevail. By this means, an Alternation of Compression and Dilatation will be produc'd in both, answering the *respiratory* motion by which a motion will be communicated, which, as soon as the Organs by which it shou'd be regulated are compleated, will in the Body of the *Pullus* be *regular* and *circulatory*.

Fabricius ab *Aquapendente*, and after him, our Great Dr. *Harvey*, have assign'd divers Uses to this Cavity or Air Vesicle, the Extravagance of which have perhaps deterr'd others from enquiring so much into the Use, as the Importance of it requir'd. But tho' I can't agree to that *Perspiration*, *Refrigeration*, and *Respiration*, which they make it the Instrument of; yet perhaps the *Air*, that was inclos'd in that *Cavity*, may thro' the augmentation of the Body of the *Pullus*, and its own *Rarefaction* (which is at last so great as to occupy half the Shell) break the *Membrane*, which separated it from the *Pullus*, and thereby give so much *Respiration* as to form the *chirping Voice*, which is often heard before the breaking of the Shell; and with it give

Digitized by Google

an Addition of Strength to enable it to break the Shell. But how it shou'd respire sooner, is to me inconceivable.

There are many Problems of great seeming difficulty, the Solutions of which flow naturally from what has been laid down here: But intending to prosecute this Subject farther, and to treat of the Impediments of Respiration, and the Consequences of Respiration obstructed or intermitted, I shall reserve 'em for that opportunity, and content my self here to attempt the *Harveyan* Problem only, which has given abundance of Authors so much perplexity.

That Incomparable Philosopher enquires, *Why a* Fœtus, *taken out of the* Uterus *with the* Membranes *intire, shall live in Water some hours without communication with the* external Air; *whereas if it be taken out and suffer'd once to breath, it can't afterwards survive a moment without the benefit of* Respiration.

Granting the Fact to be as he has deliver'd it, which yet is not so in all cases, the main difficulty is grounded on a mistake, which from the stating of the Question I find this Great Man to have slipt into. For he thinks, that a *Fœtus* is sooner suffocated after having once breath'd, than if it had not breath'd at all, and that by breathing it had contracted something which render'd it more perishable. *Idem tamen secundis curis*, (says he) *si semel* aerem *intrâ* Bulmones *attraxerit, postea ne momentum quidem temporis absq; eâ durare possit, sed confestim moriatur.* And presently after; *Siquidem constat, fœtum, postquam* cum semel *hauserit*, citius *suffocari, quam cum*

ab illo prorſus *accebatur*. The Doctor obſerving a *Fœtus* to live longer without Reſpiration, and to diſpence better with the want of Air while included in the Membranes intire, than it cou'd afterwards; infers thence, that the Air does in the firſt Act of Inſpiration impreſs upon the Lungs ſome quality, which renders it ever after more indiſpenſably neceſſary. But allowing his Obſervation, I muſt yet deny his Inference to be good: For deprive a *Fœtus* of means of reſpiring, and then take it out of the Membranes, and it ſhall be as ſoon ſuffocated, as if it had reſpired before. This proves, that this neceſſity of intercourſe with the Air, by way of the Lungs, is not the Offspring, but the Parent of Reſpiration, and that, that Learned Man was drawn into a Fallacy of *Non cauſa pro cauſa*.

The reaſon of this Neceſſity is the preſſure of the external Air upon the Surface of the Body, from which it was defended by the interpoſition of the Membranes and the Humors contain'd, which are not ſo compreſſible as the Body of the *Fœtus* it ſelf. So ſoon therefore as the *Fœtus* is excluded, and expos'd to the immediate contact of the ambient Atmoſphere, the Veſſels and all the Cavities of the Body muſt neceſſarily be ſo compreſs'd, that the Fluids can't have room for motion, and conſequently the *Fœtus* cou'd have no Life, if Nature had not contriv'd by the motion of the *Thorax* to remove and admit that preſſure alternately, and thereby to impreſs a motion on the Fluids, which is the Spring of Life. But this motion of the *Thorax* being any way ſuppreſs'd, the equal preſſure of the Atmoſphere

Digitized by Google

sphere on all parts occasions a total Cessation of Motion, which is Death.

I shall prosecute this Subject no farther now, nor trouble the Reader with any Apology, for dissenting from those Great Men herein named; because, I hope, I have done it with modesty, and all the respect due to so great Authorities, and have assign'd nothing which is not matter of Fact uncontroverted, or deduc'd from it by plain mechanical Necessity.

Some

Some Thoughts and Experiments concerning Vegetation. *By* John Woodward, *M. D. of the College of Physicians, and R. S. and Professor of Physick in* Gresham College.

THE *Ancients* generally intituled the *Earth* to the Production of the *Animals*, *Vegetables*, and *other Bodies* upon and about it; and that for that reason 'twas, that they gave it so frequently the Epithets of *Parent* and *Mother* *. They were of opinion, that it furnished forth the *Matter* whereof *those Bodies* consist; and received it all back again at their Dissolution for the Composure of *others*. Even those who asserted *four Elements*, supposed that the *Earth* was the *Matter* that *constituted* those Bodies; and that *Water* and the *rest*, serv'd only for the *Conveyance* and *Distribution* of that *Matter*, in order to the *forming* and *composition* of them. 'Tis true, *Thales*, a Philosopher of the first rank in those early Ages, has been thought to have Sentiments very different from these; but that without just Grounds, as I think I have sufficiently proved in another Paper, which I am ready to produce.

* *Terra Parens.* Τὴ μήτηρ πάντων. *Terra Mater.*

But

Digitized by Google

But tho' *Antiquity* thus gave its *Vote* for *Terrestrial Matter*, several of the *Moderns*, and some of very *great Name* too, both *here* and *abroad*, have gone quite counter, and given *theirs* in behalf of *Water*. The *Dignity* of the *Persons* that have espoused it, as well as their *Numbers*, renders this Doctrine very considerable, and well worth our enquiring into. The great Restorer of *Philosophy* in this last Age, my Lord *Bacon*, is of opinion, *That for Nourishment of* Vegetables, *the Water is almost all in all*; *and that the Earth doth but keep the Plant upright, and save it from over-heat, and over-cold* †. Others there are who are still more express; and assert Water to be the only Principle or Ingredient of all natural things. They suppose that, by I cannot tell what Process of Nature, Water is *transmuted* into *Stones*, into *Plants*, and, in brief, all other Substances whatever. *Helmont*, * particularly, and his *Followers*, are very positive in this; and offer some *Experiments* to render it credible. Nay, a very *extraordinary Person* of our our own *Nation* † tries those *Experiments* over again; and discovers a great Propensity to the same Thoughts and Opinion they had; declaring for this *Transmutation of Water* into *Plants* and *other Bodies*, tho' with great Modesty and Deference, which was his usual manner.

† *Nat. Hist. Cent.* 5. §. 411.

* *Complexionum atque Mistion. Element. Figm.*

† Mr. *Boyl*, *Scept. Chym. par.* 2.

The *Experiments* they insist upon are chiefly *two*; the *first* is, that *Mint*, and several *other Plants*

Digitized by Google

Plants prosper and thrive very greatly in *Water*. The *other* is this; they take a certain quantity of *Earth*, and *bake* it in an *Oven*; then they weigh it, and put it into an *Earthen Pot*. Having well water'd this *Earth*, they make choice of some fit *Plant*, which, being first carefully *weigh*'d, they *set* in it. There they let it grow, continuing to *water* it for some time, 'till 'tis much advanced in *bigness*: Then they take it up; and tho' the *Bulk* and *Weight* of the *Plant* be much greater than when *first set*, yet upon *baking* the *Earth*, and *weighing* it, as at first, they find it little or not at all diminished in *weight*; and therefore conclude, 'tis not the *Earth* but *Water*, that nourishes and is *turn'd* into the Substance of the *Plant*.

I must confess I cannot see how *this Experiment* can ever be made with the *nicety* and *justness* that is requisite, in order to *build* upon it so *much* as *these Gentlemen* do. 'Tis hard to weigh *Earth* in that *quantity*, or *Plants* of the *size* of those they mention, with any great *exactness*; or to *bake* the Earth with that *accuracy*, as to reduce it *twice* to just the *same Dryness*. But I may wave all this; for tho' the *Experiment* be never so easily practicable, and all the Accidents of it exactly as they set forth, yet nothing like what they *infer* can possibly be concluded from it; unless *Water*, which they so plentifully bestow upon the *Plant* in *this Experiment*, be *pure*, *homogeneous*, and not charged with any *terrestrial Mixture*; for if it be, the Plant after all may owe its *growth* and *increase* intirely to *that*.

Some

Digitized by Google

Some *Waters* are indeed so very *clear* and *transparent*, that one would not easily suspect any *terrestrial Matter* were latent in them; but they may be *highly saturated* with such *Matter*, tho' the Eye be not presently able to descry or discern it. 'Tis true, *Earth* is an *Opake Body*; but it may be so far dissolved, reduced to so extreme small Particles, and these so *diffused* through the *watery Mass*, as not sensibly to impede *Vision*, or render the Water much the less *diaphanous*. *Silver* is an *Opake*, and indeed a very *dense Body*; and yet, if perfectly *dissolved* in *Sp.* of *Nitre*, or *Aqua Fortis*, that is *rectified* and thorowly *fine*, it does not *darken* the *Menstruum*, or render it less *pellucid* than before *. And other Instances there are, that oftentimes *great quantities* of *Opake Matter* are sustain'd in *Fluids*, without considerably striking the *Eye*, or being perceived by it. So that were there *Water* any where found so *pure*, that the quickest Eye could discover in it no *terestrial Intermixture*; that would be far short of a *Proof*, that in reality there was *none*.

* *Provided the* Silver *be* pure *and absolutely* refin'd: *For the least admixture of* Copper *will produce a* blue Tincture *in the* Menstruum; *as* that *of some* other Bodies, *one* different.

But after all, even the *cleareſt Water* is very far from being *pure* and wholly *defecate*, in any part of the World that I can learn. For Ours here, I have had an Opportunity of examining it over a good part of *England*; and cannot say I ever met with any, that, however fresh and newly taken out of the Spring, did not

Digitized by Google

not exhibit, even to the naked Eye, great numbers of exceeding ſmall terreſtrial Particles diſſeminated through all parts of it. Thicker and craſſer Water exhibits them in ſtill greater Plenty.

Theſe are of two general kinds. The one a vegetable terreſtrial Matter, conſiſting of very different Corpuſcles; ſome whereof are proper for the formation and increment of one ſort of Plant, and ſome of another; as alſo ſome for the nouriſhment of one part of the ſame Plant, and ſome of another. The other kind of Particles ſuſtain'd in Water are of a Mineral Nature. Theſe likewiſe are of different ſorts. In ſome Springs we find Common Salt, in others *Vitriol*, in others *Alum*, *Nitre*, *Sparr*, *Ochre*, &c. nay, frequently ſeveral of theſe, or other Minerals, all in the ſame Spring; the Water as it drains and paſſes thorough the *Strata* of Stone, Earth, and the like, taking up and bearing along ſuch looſe Mineral Corpuſcles, as it meets with in the Pores and Interſtices of thoſe *Strata*, and bringing them on with it quite to the Spring. All Water whatever is much charged with the Vegetable Matter, this being fine, light, and eaſily moveable. For the Mineral, the Water of Springs contains more of it than that of Rivers, eſpecially when at diſtance from their Sources; and that of Rivers more than the Water that falls in Rain. This I have learn'd from ſeveral Trials, which I muſt not give Account of here; my Drift in this place being only to evince the Exiſtence of terreſtrial Matter in Water.

Any

Digitized by Google

Any one who deſires farther ſatisfaction in this, may eaſily obtain it, if he only put Water into a clear Glaſs Viol, ſtopping it cloſe, to keep Duſt and other exterior Matter out, and letting it ſtand, without ſtirring it for ſome Days: He'll then find a conſiderable Quantity of terreſtrial Matter in the Water, however pure and free it might appear when firſt put into the Viol. He'll in a very ſhort time obſerve, as I have frequently done, the Corpuſcles that were at firſt, while the Water was agitated and kept in motion, ſeparate, and hardly viſible *, by degrees, as the Water permits, by its becoming more ſtill and at reſt, aſſembling and combining together; by that means forming ſomewhat larger and more conſpicuous *Moleculæ*. Afterwards he may behold theſe joining and fixing each to other, by that means forming large thin Maſſes, appearing like *Nubeculæ*, or Clouds in the Water; which grow more thick and opake, by the continual appulſe and accretion of freſh Matter. If the ſaid Matter be chiefly of the Vegetable kind, 'twill be ſuſtain'd in the Water; and diſcover at length a green Colour, becoming ſtill more and more of that Colour, I mean an higher and more ſaturate Green, as the Matter thickens and encreaſes. That this *Matter* inclines ſo much to that *Colour*, is the leſs ſtrange, ſince we ſee ſo large a ſhare of it, when conſtituting Vegetables wearing the ſame Colour in them. But if there be any conſiderable quantity of meer Mineral Matter in the Water, this, being of

* *To ſay nothing of thoſe that were not diſcernible.*

Digitized by Google

of a greater specifick Gravity than the Vegetable, as the Particles of it unite and combine in such Number, 'till they form a *Molecula*, the Impetus of whose Gravity surpasses that of the Resistance of the Water, subsides a great deal of it to the *bottom*. Nor does it only fall down it self, but frequently entangling with the *Vegetable Nubecula*, forces them down along with it.

The Reason why Bodies, when dissolved and reduced to extreme small Parts, are sustain'd in Liquors that are of less specifick Gravity than those Bodies are, hath been pointed at by a late ingenious Member of this Society *. He is indeed far from having adjusted all the *Momenta* of this Affair; however it must be admitted, that, in the *dividing* or *solution* of Bodies, their Surfaces do not decrease in the same Proportion that their Bulk does. Now the Gravity of a Body, which is the Cause of its sinking or tendency downwards, is commensurate to its Bulk; but the Resistance that the Liquor makes, is proportion'd, not to the Bulk, but to the extent of the Surface of the Body immersed in it. Whence 'tis plain, a Body may be so far divided, that its Parts may be sustain'd in a Fluid, whose specifick Gravity is less than that of the said Body. Nay, 'tis Matter of Fact that they frequently are so; and we daily see *Menstrua* supporting the Parts of *Metals*, and other Bodies, that are of six, ten, nay, almost twenty times the Spec. Grav. of those *Menstrua*. And as the Parts of Bodies when divided, are thus supported in a Fluid;

* Mr. *W. Molineux*, *Philos. Transf. No.* 181.

Digitized by Google

so when they occur and unite again, they must sink of course, and fall to the Bottom.

Upon the whole, 'tis palpable and beyond reasonable Contest, that *Water* contains in it a very considerable Quantity of terrestrial Matter. Now the Question is, to which of these, the Water, or the Earthy Matter sustain'd in it, Vegetables owe their Growth and Augment: For deciding of which, I conceive the following Experiments may afford some Light; and I can safely say, they were made with due Care and Exactness.

Anno 1691.

I chose several *Glass Viols*, that were all, as near as possible, of the same shape and bigness. After I had put what Water I thought fit into every one of them, and taken an Account of the weight of it, I strain'd and ty'd over the Orifice of each Viol, a Piece of Parchment, having an hole in the middle of it, large enough to admit the Stem of the Plant I design'd to set in the Viol, without confining or straightning it so as to impede its *Growth*. My Intention in this, was to prevent the inclosed Water from evaporating, or ascending any other way than only thorough the Plant to be set therein. Then I made choice of several Sprigs of Mint, and other Plants, that were, as near as I could possibly judge, alike fresh, sound, and lively. Having taken the weight of each, I placed it in a Viol, order'd as above; and as the Plant imbib'd and drew off the Water, I took care to add more of the same

Digitized by Google

same from time to time, keeping an Account of the weight of all I added. Each of the Glasses were, for better distinction, and the more easie keeping a Register of all Circumstances, noted with a different Mark or *Letter*, *A*, *B*, *C*, *&c.* and all set in a Row in the same Window, in such manner that all might partake alike of *Air*, *Light*, and *Sun*. Thus they continued from *July* the Twentieth, to *October* the Fifth, which was just Seventy seven-Days. Then I took them out, weigh'd the Water in each Viol, and the Plant likewise, adding to its weight that of all the Leaves that had fallen off during the time it stood thus. And Lastly, I computed how much each Plant had gain'd; and how much Water was spent upon it. The Particulars are as follows.

'(A.) *Common Spear-Mint*, set in *Spring-Water*. The Plant weighed when put in *July* 20. just 27 Grains; when taken forth, *Octob.* 5. 42 Grains: So that in this space of 77 Days, it had gained in weight 15 Grains.

'The whole Quantity of Water expended, during these 77 Days, amounted to 2558 Gr. Consequently the weight of the Water taken up, was $170\frac{8}{15}$ times as much as the Plant had got in weight.

'(B.) *Common Spear-Mint*, *Rain-Water*. The Mint weigh'd, when put in, Gr. $28\frac{1}{4}$; when taken out Gr. $45\frac{3}{4}$, having gain'd in 77 Days Gr. $17\frac{1}{2}$.

Digitized by Google

'The Dispendium of the Water Gr. 3004, 'which was 171 $\frac{2}{3}$ $\frac{1}{5}$ times as much as the Plant 'had received in weight.

'(C.) *Common Spear-mint, Thames-water.* The 'Plant when put in, Gr. 28, when taken forth, 'Gr. 54. So that in 77 Days it had gained 'Gr. 26.

'The Water expended, amounted to Gr. '2493, which was 95 $\frac{2}{13}$ $\frac{1}{6}$ times as much as the 'additional weight of the Mint.

'(D.) *Common Solanum*, or *Night-shade*: '*Spring-water.* The Plant weigh'd, when put 'in, Gr. 49; when taken out 106, having 'gain'd in 77 Days 57 Gr.

'The Wat. expended during the said time, 'was 3708 Gr. which was 65 $\frac{1}{7}$ times as much 'as the Augment of the Plant.

'*This Specimen* had several *Buds* upon it, 'when first set in the Water. *These* in some 'Days became fair *Flowers*, which were at 'length succeeded by *Berries*.

'(E.) *Lathyris seu Cataputia Gerh.* *Spring-* '*Water.* It weigh'd, when put in, Gr. 98. 'when taken forth, Gr. 101 $\frac{1}{2}$. The additional 'weight for this whole 77 Days, being but 'Gr. 3 $\frac{1}{2}$.

'The Quantity of Water spent upon it, du- 'ring that time, Gr. 2501. which is 714 $\frac{4}{7}$ times as much as the Plant was augmented.

Several other Plants *were try'd, that did* not thrive *in* Water, *or succeed any better than the* Cataputia *foregoing*: *But*

Digitized by Google

But 'tis beſides my purpoſe to give a particular Account *of them here.*

(F, G) *Theſe Two Viols* were fill'd, the former (F) with *Rain*, the other with *Spring-water*, at the ſame time, as thoſe above-mention'd were; and ſtood as long as they did. But they had neither of them any Plant; my Deſign in theſe being only to inform my ſelf, whether any Water exhaled out of the Glaſſes, otherwiſe than *through* the Bodies of the Plants. The Orifices of theſe two Glaſſes were cover'd with Parchment; each piece of it being perforated with an hole of the ſame bigneſs with thoſe of the Viols above. In this I ſuſpended a bit of Stick about the thickneſs of the Stem of one of the aforeſaid Plants, but not reaching down to the Surface of the included Water. I put them in thus, that the Water in theſe might not have more Scope to evaporate than that in the other Viols. Thus they ſtood the whole 77 Days in the ſame Window with the reſt; when, upon Examination, I found none of the Water in theſe waſted or gone off. Tho' I obſerved both in theſe, and the reſt, eſpecially after hot Weather, ſmall Drops of Water, not unlike Dew, adhering to the Inſides of the Glaſſes, that Part of them, I mean, that was above the Surface of the enclosed Water.

The Water in theſe two Glaſſes that had no Plants in them, at the end of the Experiment, exhibited a larger Quantity of terreſtrial Matter than that in any of thoſe that had the Plants in them did. The Sediment at the bottom of the Viols was greater; and the

Digitized by Google

Nubeculæ diffus'd through the Body of the Water thicker. And of that which was in the others, some of it proceeded from certain small Leaves that had fallen from that part of the Stems of the Plants that was within the Water, wherein they rotted and dissolved. The terrestrial Matter in the Rain-water was finer than that in the Spring-water.

Anno 1692.

The Glasses made use of in this, were of the same sort with those in the former Experiment; and cover'd over with Parchment in like manner. The Plants here were all *Spearmint*; the most kindly, fresh, sprightly Shoots I could chuse. The Water, and the Plants were weigh'd as above; and the Violets set in a Line, in a South Window; where they stood from *June* 2d, to *July* 28. which was just 56 Days.

(H.) *Hyde-park Conduit-water*, alone. The *Mint* weighed, when put in, 127 Gr. when taken out, 255 Gr. The whole Quantity of Water expended upon this Plant, amounted to 14190 Gr.

'This was all along a very kindly Plant; and had run up to above two Foot in height. It had shot but one considerable collateral Branch; but had sent forth many and long Roots, from which sprung very numerous, tho' small and short, lesser Fibres. These lesser Roots came out of the larger on two opposite sides, for the most part; so that each

'Root,

Digitized by Google

'Root, with its *Fibrillæ*, appear'd not unlike 'a small Feather. To these *Fibrillæ* adher'd 'pretty much terrestrial Matter. In the Wa-'ter which was at last thick and turbid, was a 'green Substance resembling a fine thin *Con-'ferva.*

'(I.) The *same Water*, alone. The *Mint* 'weigh'd, when put in, 110 Gr. when taken 'out, 249. Water expended, 13140 Gr.

'This Plant was as kindly as the former, 'but had shot no collateral Branches. Its 'Roots, the Water, and the green Substance, 'all much as in the former.

'(K.) *Hyde-Park, Conduit-water*, in which 'was dissolved an Ounce and half of *Common 'Garden-earth.* The *Mint* weigh'd, when put 'in, 76 Gr. when taken out 244 Gr. Water 'expended, Gr. 10731.

'This Plant, tho' it had the Misfortune to 'be annoy'd with many small Insects that hap-'pened to fix upon it; yet had shot very con-'siderable collateral Branches; and at least 'as many Roots as either that in H or I; 'which had a much greater Quantity of ter-'restrial Matter adhering to the Extremities 'of them. The same green Substance here, 'that was in the two preceding.

'(L.) *Hyde-Park Water*, with the same Quan-'ty of Garden-mould as in the former. The '*Mint* weigh'd, when put in, 92 Gr. when 'taken out 376 Gr. The Water expended 14950 Gr.

'This Plant was far more flourishing than 'any of the precedent; had several very con-

Digitized by Google

'siderable collateral Branches, and very numerous Roots, to which terrestrial Matter 'adhered very copiously.

'The Earth in both these Glasses was very sensibly and considerably wasted, and less 'than when first put in. The same sort of 'green Substance here as in those above.

'(M.) *Hyde-Park Water*, distilled off with a 'gentle Still. The *Mint* weigh'd when put in, '114 Gr. when taken out 155. The Water 'expended, 8803 Gr.

'This Plant was pretty kindly; had two 'small collateral Branches, and several Roots, 'tho' not so many as that in H or I, but as 'much terrestrial Matter adhering to them 'as those had. The Water was pretty thick; 'having very numerous small terrestrial Particles swimming in it, and some Sediment at 'the bottom of the Glass. This Glass had 'none of the green Matter above-mentioned, 'in it.

'(N.) The Residue of the Water, which re'main'd in the *Still* after that in M, was di'still'd off. It was very turbid, and as high'coloured (reddish) as ordinary Beer. The '*Mint* weigh'd, when put in, 81 Gr. when 'taken out, 175 Gr. Water expended, 4344 'Gr. This Plant was very lively; and had 'sent out six collateral Branches, and several Roots.

(O.) *Hyde-Park Conduit-water*, in which was dissolved a Drachm of Nitre. The Mint set in this suddenly began to wither and decay; and

Digitized by Google

and died in a few Days: As likewise did two more Sprigs, that were set in it, successively. In another Glass I dissolved an Ounce of good Garden-mould, and a Drachm of Nitre; and in a third, half an Ounce of Wood-ashes, and a Drachm of Nitre; but the Plants in these succeeded no better than in the former. In other Glasses I dissolved several other sorts of Earths, Clays, Marles, and variety of Manures, *&c.* I set Mint in distill'd Mint-water; and other Experiments I made, of several kinds, in order to get Light and Information, what hastened or retarded, promoted or impeded Vegetation; but these do not belong to the Head I am now upon.

(P.) *Hyde-Park Conduit-water.* In this I fix'd a Glass Tube about ten Inches long, the Bore about one sixth of an Inch in Diameter, fill'd with very fine and white Sand, which I kept from falling down out of the Tube into the Viol, by tying a thin piece of Silk over that end of the Tube that was downwards. Upon Immersion of the lower end of it into the Water, this by little and little ascended quite to the upper Orifice of the Tube. And yet, in all the fifty six Days which it stood thus, a very inconsiderable Quantity of Water had gone off, *viz.* scarce twenty Grains; tho' the Sand continued moist up to the top till the very last. The Water had imparted a green Tincture to the Sand, quite to the very top of the Tube. And, in the Viol, it had precipitated a greenish Sediment, mix'd with black. To the bottom and sides of the Tube, as far as 'twas immers'd in the Water, adher'd

her'd pretty much of the green Substance described above. Other like Tubes I fill'd with Cotton, Lint, Pith of Elder, and several other porous Vegetable Substances; setting some of them in clear Water; others in Water tinged with Saffron, Cochinele, *&c.* And several other Trials were made, in order to give a mechanical Representation of the motion and distribution of the Juices in Plants; and of some other *Phænomena* observable in Vegetation, which I shall not give the Particulars of here, as being not of use to my present design.

(Q, R, S,) *&c.* Several Plants set in Viols, ordered in like manner as those above, in *October*, and the following colder months. These throve not near so much; nor did the Water ascend in nigh the quantity it did in the better Seasons, in which the before recited Trials were made.

Some Reflexions upon the foregoing Experiments.

1. *In Plants of the same kind, the less they are in Bulk, the smaller the Quantity of the fluid Mass, in which they are set, is drawn off; the Dispendium of it, where, the Mass is of equal thickness, being pretty nearly proportioned to the Bulk of the Plant.* Thus that in the Glass mark'd A, which weig'd only 27 Gr. drew off but 2558 Grains of the Fluid; and that in B, which weigh'd only 28¼, took up but 3004 Grs. whereas that in H, which weigh'd

weigh'd 127 Grains, spent 14190 Gr. of the Liquid Mass.

The Water seems to ascend up the *Vessels* of Plants, in much the same manner as up a Filtre, and 'tis no great wonder that a larger Filtre should draw off more Water than a lesser; or that a Plant that has more and larger Vessels, should take up a greater share of the Fluid in which it is set, than one that has fewer and smaller ones can. Nor do I note this as a thing very considerable in it self, but chiefly in regard to what I am about to offer beneath; and that it may be seen that, in my other Collations of Things, I made due Allowance for this Difference.

2. *The much greatest part of the fluid Mass, that is thus drawn off and conveyed into the Plants, does not settle or abide there; but passes through the pores of them, and exhales up into the Atmosphere.* That the Water in these Experiments ascended only through the Vessels of the Plants, is certain. The *Glasses* F and G, that had no Plants in them, tho' disposed of in like manner as the rest, remain'd at the End of the Experiment, as at first; and none of the Water was gone off. And that the greatest part of it flies off from the Plant into the Atmosphere, is as certain. The least Proportion of the Water expended, was to the Augment of the Plant, as 40 or 50 to 1. And in some the weight of the Water drawn off, was 100, 200, nay, in one above 700 times as much as the Plant had received of Addition.

This

This so continual an Emission and Detachment of Water, in so great Plenty from the Parts of Plants, affords us a manifest reason why Countries that abound with Trees, and the larger Vegetables especially, should be very obnoxious to Damps, great Humidity in the Air, and more frequent Rains, than others that are more open and free. The great Moisture in the Air, was a mighty inconvenience and annoyance to those who first settled in *America*; which at that time was much overgrown with Woods and Groves. But as these were burnt and destroy'd, to make way for Habitation and Culture of the Earth, the Air mended and cleared up apace, changing into a Temper much more dry and serene than before.

Nor does this Humidity go off pure and alone; but usually bears forth with it many Parts of the same Nature with those whereof the Plant, through which it passes, consists. The *Grosser* indeed are not so easily born up into the Atmosphere; but are usually deposited on the Surface of the Flowers, Leaves, and other Parts of the Plants: Hence comes our Manna's, our Honeys, and other Gummous Exsudations of Vegetables. But the finer and lighter Parts are with greater ease sent up into the Atmosphere. Thence they are conveyed to our Organs of Smell, by the Air we draw in Respiration; and are pleasant or offensive, beneficent or injurious to us, according to the Nature of the Plants from whence they arise. And since these owe their Rise to the Water that ascends out of the Earth through the Bodies of Plants, we cannot be far to seek

for

Digitized by Google

for the Cause why they are more numerous in the Air, and we find a greater quantity of Odors exhaling from Vegetables, in warm, humid Seasons, than in any other whatever.

3. *A great part of the terrestrial Matter that is mix'd with the Water, ascends up into the Plant as well as the Water.* There was much more terrestrial Matter at the end of the Experiment, in the Water of the Glasses F and G, that had no Plants in them, than in those that had Plants. The *Garden-mould* dissolved in the Glasses K and L was considerably diminished, and carried off. Nay, the terrestrial and vegetable Matter was born up in the Tubes filled with Sand, Cotton, *&c.* in that Quantity, as to be evident even to Sense. And the Bodies in the Cavities of the other Tubes, that had their lower Ends immers'd in Water, wherein Saffron, Cochinele, *&c.* had been infused, were tinged with Yellow, Purple, *&c.*

If I may be permitted to look abroad a while, towards our Shores and Parts within the Verge of the Sea, these will present us with a large Scene of Plants, that, along with the Vegetable, take up into them meer mineral Matter also in great abundance. Such are our Sea-Purslains, the several of *Alga's*, of Sampires, and other marine Plants. These contain common Sea-salt, which is all one with the *Fossil*, in such plenty, as not only to be plainly distinguish'd on the Palate, but may be drawn forth of them in considerable quantity. Nay, there want not those who affirm, there are Plants found that will yield *Nitre*, and

and other mineral Salts; of which indeed I am not so far satisfied, that I can depend on the Thing, and therefore give this only as an hint for Enquiry.

To go on with the vegetable Matter, how apt and how much disposed this, being so very fine and light, is to attend Water in all its Motions, and follow it into each of its Recesses, is manifest, not only from the Instances above alledg'd, but many others. Percolate it withal the Care imaginable: Filter it with never so many Filtrations, yet some terrestrial Matter will remain. 'Tis true, the Fluid will be thinner every time than other, and more disingaged of the said Matter; but never wholly free and clear. I have filtred Water thorough several wholly fine and clear Sheets of thick Paper; and, after that, through very close fine Cloth twelve times doubled. Nay, I have done this over and over; and yet a considerable quantity of this Matter discover'd it self in the Water after all. Now if it thus pass Interstices, that are so very small and fine along with the Water, 'tis the less strange it should attend it in its passage through the Ducts and Vessels of Plants. 'Tis true, filtering and distilling of Water intercepts and makes it quit some of the Earthy Matter it was before impregnated withal: But then that which continues with the Water after this, is fine and light; and such consequently, as is in a peculiar manner fit for the Growth and Nourishment of Vegetables. And this is the Case of Rain-water. The Quantity of terrestrial Matter it bears up into the Atmosphere, is not great.

But

Digitized by Google

But that which it does bear up, is mainly of that light kind of vegetable Matter; and that too perfectly dissolved, and reduced to single Corpuscles, all fit to enter the Tubules and Vessels of Plants: On which Account 'tis that this Water is so very fertile and prolifick.

The Reason, why in this Proposition, I say, only a great part of the terrestrial Matter that is mix'd with the Water, ascends up with it into the Plant, is, because all of it cannot. The mineral Matter is a great deal of it, not only gross and ponderous, but scabrous and inflexible; and so not disposed to enter the Pores of the Roots. And a great many of the simple vegetable Particles by degrees unite, and form some of them small Clods or *Molecula*; such as those mention'd in H, K, and L, sticking to the Extremities of the Roots of those Plants. Others of them intangle in a looser manner; and form the *Nubecula*, and green Bodies, so commonly observed in stagnant Water. These, when thus conjoin'd, are too big to enter the Pores, or ascend up the Vessels of Plants, which singly they might have done. They who are conversant in Agriculture, will easily subscribe to this. They are well aware that, be their Earth never so rich, so good, and so fit for the Production of Corn or other Vegetables, little will come of it, unless the Parts of it be separated and loose. 'Tis on this Account they bestow the Pains they do in Culture of it, in Digging, Plowing, Harrowing, and Breaking of the Clodded Lumps of Earth. 'Tis the same way that Sea-salt, Nitre, and

other

other Salts promote Vegetation. I am sorry I cannot subscribe to the Opinion of those Learned Gentlemen, who imagine Nitre to be essential to Plants; and that nothing in the vegetable Kingdom is transacted without it. By all the Trials I have been able to make, the thing is quite otherwise; and when contiguous to the Plant, it rather destroys than nourishes it. But this Nitre and other Salts certainly do; they loosen the Earth, and separate the concreted Parts of; by that means fitting and disposing them to be assumed by the Water, and carried up into the Seed or Plant, for its Formation and Augment. There's no Man but must observe, how apt all sorts of Salts are to be wrought upon by Moisture; how easily they liquate and run with it; and when these are drawn off, and have deserted the Lumps wherewith they were incorporated, those must moulder immediately, and fall asunder of Course. The hardest Stone we meet with, if it happen, as frequently it does, to have any sort of Salt intermix'd with the Sand of which it consists, upon being expos'd to an humid Air, in a short time dissolves and crumbles all to pieces; and much more will clodded Earth or Clay, which is not of near so compact and solid a Constitution as Stone is. The same way likewise is Lime serviceable in this Affair. The Husbandmen say of it, that it does not fatten, but only mellows the Ground: By which they mean, that it does not contain any thing in it self that is of the same Nature with the vegetable Mould, or afford any Matter fit for the Formation of Plants; but meerly

Digitized by Google

meerly ſoftens and relaxes the Earth; by that means rendering it more capable of entering the Seeds and Vegetables ſet in it, in order to their Nouriſhment, than otherwiſe it would have been. The Properties of Lime are well known; and how apt 'tis to be put into Ferment and Commotion by Water. Nor can ſuch Commotion ever happen when Lime is mix'd with Earth, however hard and clodded that may be, without opening and looſening of it.

4. *The Plant is more or leſs nouriſh'd and augmented, in proportion as the Water, in which it ſtands, contains a greater or ſmaller Quantity of proper terreſtrial Matter in it.* The Truth of this Propoſition is ſo eminently diſcernible through the whole Proceſs of theſe Trials, that I think no doubt can be made of it. The *Mint* in the Glaſs C was of much the ſame Bulk and Weight with thoſe in A and B. But the Water, in which that was, being River-water, which was apparently ſtored more copiouſly with terreſtrial Matter, than the Spring or Rain-water, wherein they ſtood, were; it had thriven to almoſt double the Bulk that either of them had, and with a leſs Expence of Water too. So likewiſe the Mint in L, in whoſe Water was diſſolved a ſmall quantity of good Garden-mould, tho' it had the diſadvantage * to be leſs, when firſt ſet, than either of the Mints in H or I, whoſe Water was the very ſame with this in L, but had none of that Earth mix'd with it; yet, in a ſhort time the Plant

* *Confer. Prop.* 1. *ſupra.*

Digitized by Google

not only overtook, but much out-ſtripp'd thoſe, and at the end of the Experiment was very conſiderably bigger and heavier than either of them. In like manner the *Mint* in N, tho' leſs at the beginning than that in M, being ſet in that thick, turbid, feculent Water, that remained behind, after that, wherein M was placed, was ſtill'd off, had in fine more than doubled its original weight and bulk; and received above twice the additional Encreaſe, than that in M, which ſtood in the thinner diſtill'd Water, had done. And, which is not leſs conſiderable, had not drawn off half the Quantity of Water that that had.

Why, in the beginning of this Article, I limit the Proportion of the Augment of the Plant to the Quantity of proper terreſtrial Matter in the Water, is, becauſe all, even the vegetable Matter, to ſay nothing of the Mineral, is not proper for the Nouriſhment of every Plant. There may be, and doubtleſs are, ſome Parts in different Species of Plants, that may be much alike, and ſo owe their Supply to the ſame common Matter; but 'tis plain all cannot. And there are other Parts ſo differing, that 'tis no ways credible they ſhould be form'd all out of the ſame ſort of Corpuſcles. So far from it, that there want not good Indications, as we ſhall ſee by and by, that every kind of Vegetable requires a peculiar and ſpecifick Matter for its Formation and Nouriſhment. Yea, each Part of of the ſame Vegetable does ſo; and there are very many and different Ingredients go to the Compoſition of the ſame individual Plant.

If

Digitized by Google

If therefore the Soil, wherein any Vegetable or Seed is planted, contains all or most of these Ingredients, and those in due quantity, 'twill grow and thrive there; otherwise 'twill not. If there be not as many sorts of Corpuscles as are requisite for the Constitution of the main and more essential Parts of the Plant, 'twill not prosper at all. If there be these, and not in sufficient Plenty, 'twill starve, and never arrive to its natural Stature: Or if there be any the less necessary and essential Corpuscles wanting, there will be some Failure in the Plant; 'twill be defective in Taste, in Smell, in Colour, or some other way. But tho' a Tract of Land may happen not to contain Matter proper for the Constitution of some one peculiar kind of Plant; yet it may for several others, and those much differing among themselves. The vegetative Particles are commix'd and blended in the Earth, with all the diversity and variety, as well as all the uncertainty conceivable. I have given some Intimations of this elsewhere †, and shall not repeat them here, but hope in due time to put them into a much better Light than that they there stand in.

† *Nat. Hist. Earth*, p. 228. & seq.

It is not possible to imagine, how one uniform, homogeneous Matter, having its Principles or Original Parts all of the same Substance, Constitution, Magnitude, Figure, and Gravity, should ever constitute Bodies so egregiously unlike, in all those respects, as Vegetables of different kinds are; nay, even as the different Parts of the same Vegetable. That one should carry a resinous, another a

milky, a third a yellow, a fourth a red Juice, in its Veins; one afford a fragrant, another an offenſive Smell; one be ſweet to the Taſte, another bitter, acid, acerbe, auſtere, *&c.* that one ſhould be nouriſhing, another poiſonous, one purging, another aſtringent: In brief, that there ſhould be that vaſt difference in them, in their ſeveral Conſtitutions, Makes, Properties, and Effects, and yet all ariſe from the very ſame ſort of Matter, would be very ſtrange. And, to note by the by, this Argument makes equally ſtrong againſt thoſe, who ſuppoſe meer Water the Matter out of which all Bodies are form'd.

The *Catapuſia* in the Glaſs E received but very little Encreaſe, only three Grains and an half all the while it ſtood, tho' 2501 Grains of Water were ſpent upon it. I will not ſay the reaſon was, becauſe that Water did not contain in it Matter fit and proper for the Nouriſhment of that peculiar and remarkable Plant. No, it may be the Water was not a proper *Medium* for it to grow in; and we know there are very many Plants that will not thrive in it. Too much of that Liquor, in ſome Plants, may probably hurry the terreſtrial Matter thorough their Veſſels too faſt for them to arreſt and lay hold of it. Be that as it will, 'tis moſt certain there are peculiar Soils that ſuit particular Plants. In *England*, Cherries are obſerved to ſucceed beſt in *Kent*; Apples in *Herefordſhire*; Saffron in *Cambridgeſhire*; Wood in two or three of our *Midland Counties*; and Teazles in *Somerſetſhire*. This is an Obſervation that hath held in all Parts, and indeed in all Ages of

the

the World. The most ancient Writers of Husbandry * took notice of it; and are not wanting in their Rules for making choice of Soils suited to the Nature of each kind of Vegetable they thought valuable, or worth propagating.

* *Vid. Varronem, Columellam, & reliquos Rei Rusticæ Scriptores.*

But, which is a further Proof of what I am here endeavouring to advance, that Soil that is once proper and fit for the Production of some one sort of Vegetable, does not ever continue to be so. No, in Tract of time it loses that Property; but sooner in some Lands, and later in others: This is what all who are conversant in these things know very well. If Wheat, for Example, be sown upon a Tract of Land that is proper for that Grain, the first Crop will succeed very well; and perhaps the second, and the third, as long as the Ground is in Heart, as the Farmers speak; but in a few Years 'twill produce no more, if sowed with that Corn: Some other Grain indeed it may, as Barly. And after this has been sown so often, that the Land can bring forth no more of the same, it may afterwards yield good Oats; and, perhaps, Pease after them. At length 'twill become barren; the vegetative Matter, that at first it abounded withal, being educed forth of it by those successive Crops, and most of it born off. Each sort of Grain takes forth that peculiar Matter that is proper for its own Nourishment. First, the Wheat draws off those Particles that suit the Body of that Plant; the rest lying all quiet and undisturbed the while. And

Digitized by Google

when the Earth has yielded up all them, those that are proper for Barly, a different Grain, remain still behind, 'till the successive Crops of that Corn fetch them forth too. And so the Oats, and Pease, in their Turn; 'till in fine all is carried off, and the Earth in great measure drain'd of that sort of Matter.

After all which, that very Tract of Land may be brought to produce another Series of the same Vegetables; but never 'till 'tis supplied with a new Fund of Matter, of like sort with that it at first contain'd. This Supply is made several ways: By the Grounds lying fallow for some time, 'till the Rain has pour'd down a fresh Stock upon it: Or, by the Tiller's Care in manuring of it. And for farther Evidence that this Supply is in reality of like sort, we need only reflect a while upon those Manures that are found by constant experience best to promote Vegetation, and the Fruitfulness of the Earth. These are chiefly either parts of Vegetables, or of Animals; which indeed either derive their own Nourishment immediately from vegetable Bodies, or from other Animals that do so. In particular, the Blood, Urine, and Excrements of Animals; Shavings of Horns, and of Hoofs; Hair, Wool, Feathers; calcin'd Shells; Lees of Wine, and of Beer; Ashes of all sorts of vegetable Bodies; Leaves, Straw, Roots, and Stubble, turn'd into the Earth by plowing or otherwise, to rot and dissolve there: These, I say, are our best Manures; and, being vegetable Substances, when refunded back again into the Earth, serve for the Formation of other like Bodies.

Not

Digitized by Google

Not wholly to confine our Thoughts to the Fields, let us look a while into our Gardens; where we ſhall meet with ſtill further Confirmations of the ſame thing. The Trees, Shrubs, and Herbs cultivated in theſe, after they have continued in one Station, 'till they have derived thence the greater part of the Matter fit for their Augment, will decay and degenerate, unleſs either freſh Earth, or ſome fit Manure, be applied unto them. 'Tis true, they may maintain themſelves there for ſome time, by ſending forth Roots further and further to a great extent all round, to fetch in more remote Proviſion; but at laſt all will fail; and they muſt either have a freſh Supply brought to them, or they themſelves be removed and tranſplanted to ſome Place better furniſhed with Matter for their Subſiſtence. And accordingly *Gardiners* obſerve, that Plants that have ſtood a great while in a Place, have longer Roots than uſual; part of which they cut off, when they tranſplant them to a freſh Soil, as now not of any further uſe to them. All theſe Inſtances, to paſs over a great many others that might be alledged, point forth a particular terreſtrial Matter, and not Water, for the Subject to which Plants owe their Increaſe. Were it Water only, there would be no need of Manures; or of tranſplanting them from place to place. The Rain falls in all Places alike; in this Field and in that indifferently; in one ſide of an Orchard or Garden, as well as another. Nor could there be any reaſon, why a Tract of Land ſhould yield Wheat one Year, and not the next; ſince the Rain ſhowers down alike in each. But I am

Digitized by Google

ſenſible I have carried on this Article to too great a length; which yet on ſo ample and extenſive a Subject, 'twas not eaſie to avoid.

5. *Vegetables are not form'd of Water; but of a certain peculiar Terreſtrial Matter.* It hath been ſhewn, that there is a conſiderable Quantity of this Matter contain'd both in Rain, Spring, and River-water: That the much greateſt part of the fluid Maſs that aſcends up into Plants, does not ſettle or abide there, but paſſes through the Pores of them, and *exhales* up into the Atmoſphere: That a great part of the terreſtrial Matter, mix'd with the Water, paſſes up into the Plant along with it; and that the Plant is more or leſs augmented in proportion, as the Water contains a greater or ſmaller Quantity of that Matter. From all which we may very reaſonably infer, that *Earth, and not Water, is the Matter that conſtitutes Vegetables.* The Plant in E drew up into it 2501 Grains of the fluid Maſs; and yet had received but Gr. 3 and a half of Increaſe from all that. The Mint in L, tho' it had at firſt the diſadvantage to be much leſs than that in I; yet being ſet in Water wherewith Earth was plentifully mix'd, and *that* in I *only in Water* without any ſuch additional Earth, it had vaſtly outgrown the other, weighing at laſt 145 Gr. more than that did, and ſo having gain'd about twice as much as that had. In like manner that in K, tho' 'twas a great deal leſs than when put in that in I, and alſo was impair'd and offended by Inſects; yet being planted in Water wherein Earth was diſſolved, whereas the Water in which it ſtood

Digitized by Google

ſtood had none, it not only over-took, but conſiderably ſurpaſs'd the other; weighing at laſt 29 Gr. more than that in I, and yet had not expended ſo much Water as that by above 2400 Gr. The Plant in N, tho' at firſt a great deal leſs than that in M; yet being ſet in the foul craſs Water that was left in the Still, after that, in which M was ſet, was drawn off, in Concluſion had gain'd in weight above double what that in the finer and thinner Water had. The Proportion of the Augment of that Plant that throve moſt was, to the fluid Maſs ſpent upon it, but as 1 to 46. In others, 'twas but as 1 to 60, 100, 200; nay, in the Cataputia, 'twas but as 1 to 714. The Mint in B took up 39 Gr. of Water a-day, one day with another; which was much more than the whole weight of the Plant originally; and yet, with all this, it gain'd not one fourth of a Grain a-day in weight. Nay, that in H took up 253 Gr. a-day of the Fluid: which was near twice as much as its original weight, it weighing, when firſt ſet in the Water, but 127 Grains. And, after all, the daily Encreaſe of the Plant was no more than Gr. $2\frac{1}{56}$.

6. *Spring, and Rain-water, contain pretty near an equal Charge of vegetable Matter; River-water more than either of them.* The Plants in the Glaſſes A, B, and C, were at firſt of much the ſame ſize and weight. At the End of the Experiment, the Mint in A had gain'd 15 Gr. out of 2558 Gr. of Spring-water; that in B, Gr. 17 and an half, out of 3004 Gr. of Rain-water; but that in C had got 26 Gr. out of only

onis 2493 Gr. of River-water. I do not found this Proposition solely upon these Trials; having made some more, which I do not relate here, that agree well enough with these. So that the Proportions here delivered, will hold for the main; but a strict and just Comparison is hardly to be expected. So far from it, that I make no doubt, but the Water that falls in Rain, at some times, contains a greater share of terrestrial Matter than that which falls at others. A more powerful and intense Heat must needs hurry up a larger quantity of that Matter along with the humid Vapors that form Rain, than one more feeble and remiss ever possibly can. The Water of one Spring may flow forth with an higher Charge of this Matter, than that of another; this depending partly upon the quickness of the Ebullition of the Water, and partly upon the Quantity of that Matter latent in the *Strata*, through which the Fluid passes, and the greater or less laxity of those *Strata*. For the same reason, the Water of one River may abound with it more than that of another. Nay, the same River, when much agitated and in commotion, must bear up more of it, than when it moves with less rapidity and violence. That there is a great quantity of this Matter in Rivers; and that it contributes vastly to the ordinary Fertility of the Earth, we have an illustrious Instance in the *Nile*, the *Ganges*, and other Rivers that yearly overflow the neighbouring Plains. Their Banks shew the fairest and largest Crops of any in the whole World. They are even loaded with the multitude of their Productions; and those

Digitized by Google

thoſe who have not ſeen them, will hardly be induced to believe the mighty Returns thoſe Tracts make in compariſon of others, that have not the Benefit of like Inundations.

7. *Water ſerves only for a Vehicle to the terreſtrial Matter, which forms Vegetables; and does not it ſelf make any addition unto them.* Where the proper terreſtrial Matter is wanting, the Plant is not augmented, tho' never ſo much Water aſcend into it. The *Cataputia* in E took up more Water than the Mint in C, and yet had grown but very little, having received only three Grains and an half of additional weight; whereas the other had received no leſs than twenty ſix Grains. The Mint in I was planted in the ſame ſort of Water as that in K was; only the latter had Earth diſſolved in the Water; and yet that drew off 13140 Gr. of the Water, gaining it ſelf no more than 139 Gr. in weight; whereas the other took up but 10731 Gr. of the Water, and was augmented 168 Gr. in weight. Conſequently that ſpent 2409 Gr. more of the Water than this in K did, and yet was not ſo much encreaſed in weight as this by 29 Gr. The Mint in M ſtood in the very ſame kind of Water as that in N did. But the Water in M having much leſs terreſtrial Matter in it than that in N had, the Plant bore up 8803 Gr. of it, gaining it ſelf only 41 Gr. the while; whereas that in N drew off no more than 4344 Gr. and yet was augmented 94 Gr. So that it ſpent 4459 Gr. of Water more than that did; and yet was not it ſelf ſo much increaſed

Digitized by Google

creaſed in weight, as that was by 53 Gr. This is both a very fair, and a very concluſive Inſtance; on which Account 'tis that I make oftner uſe of it. Indeed they are all ſo; and to add any thing further on this Head, will not be needful.

'Tis evident therefore Water is not the Matter that compoſes Vegetable Bodies. 'Tis only the Agent that conveys that Matter to them; that introduces and diſtributes it to their ſeveral Parts for their Nouriſhment. That Matter is ſluggiſh and unactive, and would lye eternally confin'd to its Beds of Earth, without ever advancing up into Plants, did not Water, or ſome like Inſtrument, fetch it forth and carry it unto them. That therefore there is that plentiful Proviſion, and vaſt Abundance of it ſupplied to all Parts of the Earth, is a mark of a natural Providence ſuperintending over the Globe we inhabit; and ordaining a due Diſpenſation of that Fluid, without the Miniſtry of which the Noble Succeſſion of Bodies we behold, *Animals*, *Vegetables*, and *Minerals*, would be all at a ſtand †. But to keep to Plants, 'tis manifeſt Water, as well on this, as upon the other Hypotheſis, is abſolutely neceſſary in the Affair of Vegetation; and it will not ſucceed without it: Which indeed gave occaſion to the Opinion, that Water it ſelf nouriſhed, and was changed into vegetable Bodies. They ſaw, tho' theſe were planted in a Soil never ſo rich, ſo happy, ſo advantageous, nothing came of it unleſs there was Water too in a conſiderable quantity

† *Conf. Nat. Hiſt. Earth*, p. 47. & ſeq. uti & p. 128, &c.

Digitized by Google

quantity. And it must be allow'd Vegetables will not come on or prosper where that is wanting: But yet what those Gentlemen inferr'd thence, was not, we see, well grounded.

This Fluid is capacitated for the Office here assign'd it several ways: By the Figure of its Parts; which, as appears from many Experiments, is exactly and mathematically Spherical; their Surfaces being perfectly polite, and without any the least Inequalities. 'Tis evident, Corpuscles of such a Figure are easily susceptible of motion, yea, far above any others whatever; and consequently the most capable of moving and conveying other Matter, that is not so active and voluble. Then the Intervals of Bodies of that Figure are, with respect to their bulk, of all others the largest; and so the most fitted to receive and entertain foreign Matter in them. Besides, as far as the Trials hitherto made inform us, the constituent Corpuscles of Water are each singly consider'd absolutely solid; and do not yield to the greatest external Force. This secures their Figure against any Alteration; and the Intervals of the Corpuscles must be always alike. By the latter, 'twill be ever disposed to receive Matter into it; and by the former, when once received, to bear it on along with it. Water is further capacitated to be a Vehicle to this Matter, by the tenuity and fineness of the Corpuscles of which it consists. We hardly know any Fluid in all Nature, except Fire, whose constituent Parts are so exceeding subtle and small as those of Water are. They'll pass

Digitized by Google

Pores and Interstices, that neither Air nor any other Fluid will. This enables them to enter the finest Tubes and Vessels of Plants, and to introduce the terrestrial Matter, conveying it to all Parts of them; whilst each, by means of Organs 'tis endowed with for the purpose, intercepts and assumes into it self such Particles as are suitable to its own Nature, letting the rest pass on through the common Ducts. Nay, we have almost every where Mechanical Instances of much the same Tenor. 'Tis obvious to every one how easily and suddenly Humidity, or the Corpuscles of Water sustained in the Air, pervade and insinuate themselves into Cords, however tightly twisted, into Leather, Parchment, Vegetable Bodies, Wood, and the like. This it is that fits them for *Hygrometers*; and to measure and determine the different quantities of Moisture in the Air, in different Places and Seasons. How freely Water passes and carries with it terrestrial Matter, through Filtres, Colatures, Distillations, *&c.* hath been intimated already.

8. *Water is not capable of performing this Office to Plants, unless assisted by a due Quantity of Heat; and this must concur, or Vegetation will not succeed.* The Plants that were set in the Glasses Q, R, S, *&c.* in *October*, and the following colder Months, had not near the quantity of Water sent up into them, or so great an additional Encrease by much, as those that were set in *June*, *July*, and the hotter. 'Tis plain Water has no power of moving it self, or rising to the vast height it does in the more tall

tall and lofty Plants. So far from this, that it does not appear from any Diſcovery yet made, that even its own Fluidity conſiſts in the inteſtine motion of its Parts; whatever ſome otherwiſe very learned and knowing Perſons may have thought. There's no need of any thing more, for ſolving all the *Phænomena* of Fluidity, than ſuch a Figure and Diſpoſition of the Parts, as Water has. Corpuſcles of that make, and that are all abſolutely Spherical, muſt ſtand ſo very tickle and nicely upon each other, as to be ſuſceptible of every Impreſſion; and, tho' not perpetually in motion, yet muſt be ever ready and liable to be put into it, by any the ſlighteſt Force imaginable. It is true, the Parts of Fire or Heat are not capable of moving themſelves any more than thoſe of Water; but they are more ſubtil, light, and active, than thoſe are, and ſo more eaſily put into motion. In fine, 'tis evident and matter of Fact, that Heat does operate upon, and move the Water, in order to its carrying on the Work of Vegetation: But how 'tis agitated it ſelf, and where the motion firſt begins, this is no fit Place to enquire.

That the Concourſe of Heat in this Work is really neceſſary, appears, not only from the Experiments before us, but from all Nature; from our Fields and Foreſts, our Gardens and our Orchards. We ſee in *Autumn*, as the Sun's Power grows gradually leſs and leſs, ſo its Effects on Plants is remitted, and their Vegetation ſlackens by little and little. Its Failure is firſt diſcernible in Trees. Theſe are raiſed higheſt above the Earth; and re-

quire

quire a more intenſe Heat to elevate the Water, charged with their Nouriſhment, to the Tops and Extremeties of them. So that for want of freſh Support und Nutriment, they ſhed their Leaves, unleſs ſecured by a very firm and hardy Conſtitution indeed, as our *ever-Greens* are. Next the Shrubs part with theirs; and then the Herbs and lower Tribes; the Heat being at length not ſufficient to ſupply even theſe, tho' ſo near the Earth, the Fund of their Nouriſhment. As the Heat returns the ſucceeding Spring, they all recruit again; and are furniſh'd with freſh Supplies and Verdure: But firſt, thoſe which are loweſt and neareſt the Earth, Herbs, and they that require a leſſer degree of Heat to raiſe the Water with its Earthy Charge into them: Then the Shrubs and higher Vegetables in their Turns; and laſtly, the Trees. As the Heat increaſes, it grows too powerful, and hurries the Matter with too great Rapidity thorough the finer and more tender Plants: Theſe therefore go off, and decay; and others that are more hardy and vigorous, and require a greater ſhare of Heat, ſucceed in their Order. By which Mechaniſm, provident Nature furniſhes us with a very various and differing Entertainment; and what is beſt ſuited to each Seaſon, all the Year round.

As the Heat of the ſeveral Seaſons affords us a different Face of Things; ſo the ſeveral diſtant Climates ſhew different Scenes of Nature, and Productions of the Earth *. The Hotter Countries yield ordinarily the largeſt and talleſt Trees; and thoſe

* *Conſ. Nat. Hiſt. Earth*, Pag. 267. & ſeq.

those in too much greater variety than the colder ever do. Even those Plants which are common to both, attain to a much greater Bulk in the Southern than in the Northern Climes. Nay, there are some Regions so bleak and chill, that they raise no Vegetables at all to any considerable size. This we learn from *Groenland*, from *Island*, and other Places of like cold Site and Condition. In these no Tree ever appears; and the very Shrubs they afford, are few, little, and low.

Again, in the warmer Climates, and such as do furnish forth Trees and the larger Vegetables, if there happen a remission or diminution of the usual Heat, their Productions will be impeded and diminished in proportion. Our late Colder Summers have given us proof enough of this. For tho' the Heat we have had, was sufficient to raise the vegetative Matter into the lower Plants, into our Corns, our Wheat, Barly, Pease, and the like; and we have had plenty of Straw-berries, Rasberries, Currans, Goosberries, and the Fruits of such other Vegetables as are low and near the Earth: Yea, and a moderate store of Cherries, Mulberries, Plumbs, Filberts, and some others that grow somewhat at a greater Height; yet our Apples, our Pears, Walnuts, and the Productions of the taller † Trees have been fewer, and those not so kindly, so thoroughly ripen'd, and brought to that Perfection they

* *The Dwarf-Apple and Pear-trees have succeeded better. And indeed in Trees of the same kind, those that keep closest to the Earth always produce the most and best Fruit. For which Reason 'tis that the Gardiners check and restrain the Growth of their better Fruit-trees, and prevent their running up to too great a Height.*

Digitized by Google

were in the former more benign and warm Seaſons. Nay, even the lower Fruits and Grains have had ſome ſhare in the common Calamity; and fallen ſhort both in Number and Goodneſs of what the hotter and kinder Seaſons were wont to ſhew us. As to our Grapes, Abricots, Peaches, Nectarins, and Figs, being tranſplanted hither out of hotter Climes, 'tis the leſs wonder we have of late had ſo general a Failure of them.

Nor is it the Sun, or the ordinary emiſſion of the Subterranean Heat only, that promotes Vegetation; but any other indifferently, according to its Power and Degree: This we are taught by our Stoves, hot Beds, and the like. All Heat is of like kind; and wherever is the ſame Cauſe, there will be conſtantly the ſame Effect. There's a Procedure in every part of Nature, that is perfectly regular and geometrical, if we can but find it out; and the further our Searches carry us, the more ſhall we have occaſion to admire this, and the better 'twill compenſate our Induſtry.

An

Digitized by Google

An Account of the Meaſure of the thickneſs of Gold upon Gilt Wire; together with a Demonſtration of the exceeding Minuteneſs of the Atoms or conſtituent Particles of Gold; as it was read before the R. Society, *by* E. Halley.

WHAT are the conſtituent parts of Matter, and how there comes to be ſo great a diverſity in the weight of Bodies, to all appearance equally ſolid and denſe, ſuch as are Gold and Glaſs, (whoſe ſpecifick Gravities are nearly as 7 to 1) ſeems a very hard Queſtion to thoſe that ſhall rightly conſider it: For from undoubted Experiment, Gravity is in all Bodies proportionable to the quantity of Matter in each; and there is no ſuch thing as a propenſion of ſome more, others leſs, towards the Earth's Center; ſince the Impediment of the Air being removed, all Bodies deſcend, be they never ſo looſe or compact in texture, with equal Velocity. It follows therefore, That there is 7 times as much Matter in Gold, as in a Piece of Glaſs of the ſame Magnitude; and conſequently, that at leaſt ſix parts of ſeven in the Bulk of of Glaſs, muſt be Pore or Vacuity: This ſome Favourers of the Atomical Philoſophy have

Digitized by Google

endeavoured to ſolve, by ſuppoſing the primary or conſtituent Atoms of Gold to be much larger than thoſe of other Bodies, and conſequently the Pores fewer; whereas in other Bodies, the great multitude of the interſperſed Vacuities does diminiſh their Weights.

Being deſirous to examine this Notion of the Magnitude of Atoms of Gold, I bethought my ſelf of the extreme Ductility of that Metal, which is ſeen in the beating of it into Leaf, and above all in the drawing fine Gilt-wire, by means whereof, I believed I might moſt exactly obtain the true thickneſs of the Coat of Gold, that appears, even with the Microſcope, ſo well to repreſent Gold it ſelf, that not the leaſt point of Silver appears through it. In order to this, I inform'd my ſelf among the Wire-drawers, what Gold they us'd to their Silver; and they told me, that the very beſt double Gilt Wire was made out of Cylidrick Ingots, 4 Inches in Circumference, and 28 Inches long, which weigh 16 Pounds Troy; on theſe they beſtow 4 Ounces of Gold, that is, to every 48 Ounces of Silver one of Gold; and that two Yards of the ſuper-fine Wire weighs a Grain. Hence at firſt ſight it appear'd, that the length of 98 Yards is in weight 49 Grains, and that a ſingle Grain of Gold covers the ſaid 98 Yards, and that the 100ooth part of a Grain is above $\frac{1}{3}$ of an Inch long; which yet may be actually divided into 10, and ſo the 1000ooth part of a Grain of Gold be viſible without a Microſcope. But being deſirous to compute the thickneſs of the Skin of Gold, by means of the ſpecifick Gravities of the Metals, *viz.*

Silver

Silver $10\frac{1}{3}$, and Gold $18\frac{2}{3}$, I found the Diameter of such Wire the $\frac{1}{386}$ part of an Inch, and its Circumference the $\frac{1}{1213}$ part; but the Gold in thickness no to exceed the $\frac{1}{134500}$ part of an Inch; whence it may be concluded, that the Cube of the hundreth part of an Inch would contain above 2433000000, (or the Cube of 1345) of such Atoms. And it may likewise be marvelled at, that Gold being stretcht to so great a degree as is here demonstrated, should yet shew it self of so even and united a Texture, as not to let the white Colour of the Silver under it appear through any the least Pores; which argues, that even in this exceeding thinness very many of those Atoms may still lie one over the other: Which is a Consideration may merit the Thoughts of this Honourable Society, as tending to examine that renowned Atomical Doctrine, which has of late much obtained among the Learned.

Digitized by Google

An Account of the ſeveral Species of Infinite Quantity, *and of the Proportions they bear one to the other, as it was read before the* Royal Society, *by.* E. Halley.

THAT all Magnitudes infinitely great, or ſuch as exceed any aſſignable Quantity, are equal among themſelves, though it it be vulgarly received for a Maxim, is not yet ſo common as it is erroneous; and the reaſon of the miſtake ſeems to be, That the Mind of Man, coming to contemplate the Extenſions of what exceeds the bounds of its Capacity, and of which the very Idea does include a negation of Limits; it comes to paſs that we acquieſce generally, and it ſuffices to ſay ſuch a Quantity is infinite.

But if we come more nearly to examine this Notion, we ſhall find, that there are really beſides infinite *Length* and infinite *Area*, no leſs than Three ſeveral ſorts of infinite Solidity; all of which are *Quantitates ſui generis*, having no more relation or proportion the one to the other, than a Line to a Plane, or a Plane to a Solid, or a Finite to an Infinite: But that among themſelves, each of thoſe Species of Infinites are in given Proportions, is what I now intend to make plain, if poſſible.

But

Digitized by Google

But first, infinite Length, or a Line infinitely long, is to be considered either as beginning at a Point, and so infinitely extended one way, or else both ways from the same Point; in which case the one, which is a beginning Infinity, is the one half of the whole, which is the Summ of the beginning and ceasing Infinity; or, as I may say, of Infinity, *a parte ante* and *a parte post*: Which is analogous to Eternity in time or duration, in which there is always as much to follow as is past, from any point or moment of Time: Nor doth the Addition or Subduction of finite Length or Space of time alter the case either in Infinity or Eternity, since both the one or the other cannot be any part of the whole.

As to infinite *Surface* or *Area*, any right Line, infinitely extended both ways on an infinite Plane, does divide that infinite Plane into equal Parts; the one to the right, and the other to the left of the said Line: But if from any Point in such a Plane, two right Lines be infinitely extended, so as to make an Angle, the infinite Area, intercepted between those infinite right Lines, is to the whole infinite Plane, as the Arch of a Circle, on the Point of Concourse of those Lines, as a Centre, intercepted between the said Lines, is to the Circumference of the Circle; or as the Degrees of the Angle to the 360 Degrees of a Circle. For Example, two right Lines meeting at a right Angle do include, on an infinite Plane, a quarter part of the whole infinite Area of such a Plane.

But if so be, two parallel infinite Lines be supposed drawn on such an infinite Plain, the

Digitized by Google

Area intercepted between them will be likewiſe infinite; but at the ſame time will be infinitely leſs, than that Space which is intercepted between two infinite Lines that are inclined, tho' with never ſo ſmall an Angle; for that in the one Caſe, the given finite diſtance of the parallel Lines diminiſhes the Infinity in one Degree of Dimenſion; whereas in a Sector, there is Infinity in both Dimenſions; and conſequently, the Quantities are the one infinitely greater than the other, and there is no proportion between them.

From the ſame Conſideration ariſe the Three ſeveral Species of infinite Space or Solidity, as has been ſaid; for a Parallelepipide, or a Cylinder, infinitely long, is greater than any finite Magnitude how great ſoever; and all ſuch Solids ſuppoſed to be formed on given Baſes, are as thoſe Baſes, in proportion to one another. But if two of theſe three Dimenſions are wanting, as in the ſpace intercepted between two parallel Planes infinitely extended, and at a finite diſtance; or with infinite Length and Breadth, with a finite Thickneſs; All ſuch Solids ſhall be as the given finite diſtances one to another: But theſe Quantities, tho' infinitely greater than the other, are yet infinitely leſs than any of thoſe, wherein all the three Dimenſions are infinite. Such are the Spaces intercepted between two inclined Planes infinitely extended; the Space intercepted by the Surface of a Cone, or the ſides of a Pyramid likewiſe infinitely continued, *&c.* of all which notwithſtanding, the Proportions one to another, and to the τὸ πᾶν or vaſt Abyſs of infinite Space (where-

14

Digitized by Google

in is the *Locus* of all things that are or can be; or to the Solid of infinite Length, Breadth, and Thickness, taken all manner of ways) are easily assignable. For the Space between two Planes, is to the whole, as the Angle of those Planes to the 360 Degrees of the Circle. As for Cones and Pyramids, they are as the Spherical Surface, intercepted by them, is to the Surface of the Sphere; and therefore Cones are as the versed Sines of half their Angles, to the Diameter of the Circle: These three sorts of infinite Quantity are analogous to a Line, Surface and Solid, and after the same manner cannot be compared, or have any proportion the one to the other.

Besides these, there are several other Species of infinite Quantity, arising from the Contemplation of Curves, and their Asymptotes; which, by reason of the difficulty of the Subject, cannot be made so plain to most Readers: But what has been already said, may be sufficient to evince what we undertook to explain.

An

An Account of Dr. Robert Hook's *Invention of the Marine Barometer, with its Deſcription and Uſes, publiſhed by order of the R. Society, by* E. Halley, *R. S. S.*

SInce it was found that the *Torricellian Tube*, commonly called the *Mercurial Barometer*, by the riſing and falling of the *Quick-ſilver* therein, doth preſage the Changes of the Air, in relation to fair and foul Weather; upon ſeveral Years obſervation of it, it has been proved and adjuſted for that purpoſe by Dr. *Robert Hook*; and there have been by him many attempts to improve the Inſtrument, and render the Minute Diviſions on the Scale thereof more ſenſible. He alſo judging that it might be of great uſe at Sea, contrived ſeveral ways to make it ſerviceable on Board Ship; one of which he explained to the *R. Society* at their weekly Meeting in *Greſham Colledge*, *January* 2. $166\frac{7}{8}$. ſince which time he hath further cultivated the Invention, and ſome Years ago produced before the ſaid *Society*, the Inſtrument I am now to deſcribe, which for its ſubtilty and uſefulneſs, ſeemeth to

Digitized by Google

to ſurpaſs all other performances of the like Nature.

'Till ſuch time as the Authors preſent Indiſpoſition will give him leave to beſtow freely his Thoughts on this Subject upon the Publick, it is the Opinion of the Society, that ſuch an account be given of this Contrivance, as may render it known, and recommend it to the Mariners uſe, for which it was principally intended.

The *Mercurial Barometer* requiring a perpendicular Poſture, and the *Quick-ſilver* vibrating therein with great violence upon any Agitation, is therefore uncapable of being uſed at Sea (though it hath lately been contrived to be made portable), ſo it remained to find out ſome other Principle, wherein the Poſition of the Inſtrument was not ſo indiſpenſably neceſſary: For this, all thoſe that uſe the Sea are obliged to the great facility Dr. *Hook* has always ſhewn, in applying Philoſophical Experiments to their proper uſes.

It is about forty Years ſince, that the *Thermometers* of *Robt. de Fluctibus*, depending on the Dilatation and Contraction of included Air by Heat and Cold, have been diſuſed, upon diſcovery that the Airs preſſure is unequal; that inequality mixing itſelf with the effects of the warmth of the Air in that Inſtrument. And inſtead thereof was ſubſtituted the ſeal'd *Thermometer*, including Spirit of Wine (firſt brought into *England*, out of *Italy*, by Sir *Robert Southwell*) as a proper Standard of the temper of the Air in relation to Heat and Cold; that Ætherial Spirit being of all the known Liquors the moſt ſuſceptible of Dilatation

Digitized by Google

tion and Contraction, eſpecially with a moderate degree of either Heat or Cold. Now this being allowed as a Standard, and the other *Thermometer* that includes Air being graduated with the ſame Diviſions, ſo as at the time when the Air was included, to agree with the Spirit-*Thermometer* in all the degrees of Heat and Cold, noting at the ſame time the preciſe height of the *Mercury* in the common Barometers: It will readily be underſtood, that whenſoever theſe two *Thermometers* ſhall agree, the preſſure of the Air is the ſame it was, when the Air was included and the Inſtrument graduated: That if in the Air-*Thermometer* the Liquor ſtand higher than the Diviſion marked thereon, correſponding with that on the Spirit-glaſs, it is an indication that there is a greater preſſure of the Air at that time, than when the Inſtrument was graduated. And the contrary is to be concluded when the Air-glaſs ſtands lower than the Spirit, *viz.* that then the Air is ſo much lighter, and the *Quick-ſilver* in the ordinary Barometer lower than at the ſaid time of Graduation.

And the ſpaces anſwering to an Inch of *Mercury* will be more or leſs, according to the quantity of Air ſo included, and the ſmallneſs of the Glaſs Cane, in which the Liquors riſes and falls, and may be augmented almoſt in any proportion, under that of the ſpecifick Gravity of the Liquor of the *Thermometer* to *Mercury*. So as to have a Foot or more for an Inch of *Mercury*, which is another great convenience.

It

Digitized by Google

It has been observed by some, that in long keeping this Instrument, the Air included either finds a means to escape, or deposites some Vapours mixt with it, or else for some other cause becomes less Elastick, whereby, in process of time, it gives the height of the *Mercury* somewhat greater than it ought; but this, if it should happen in some of them, hinders not the usefulness thereof, for that it may at any time very easily be corrected by experiment, and the rising and falling thereof are the things chiefly remarkable in it, the just height being barely a Curiosity.

In these parts of the World, long experience has told us, that the rising of the *Mercury* forebodes fair Weather after foul, and an Easterly or Northerly Wind; and that the falling thereof, on the contrary signifies Southerly or Westerly Winds, with Rain, or stormy Winds, or both; which latter it is of much more consequence to provide against at Sea than at Land; and in a Storm, the *Mercury* beginning to rise is a sure sign that it begins to abate, as has been experienced in high Latitudes both to the Northwards and Southwards of the Æquator.

The Form of this Instrument is shown in the Cut by Tab. 4. Fig. 1. wherein,

A B represents the Spirit-*Thermometer*, graduated from 0, or the freezing Point, through all the possible degrees of the Heat or Cold of the Air, at least in these Climates.

C D is the Air-*Thermometer*, graduated after the same manner with the like Degrees.

Digitized by Google

EF is a Plate applied to the side of the *Thermometer* CD, graduated into spaces answering to Inches and parts of an Inch of *Mercury*, in the common Barometers.

G, a Hand standing on the Plate at the height of the *Mercury* thereon, as it was when the Instrument was graduated, as suppose here at 29½ Inches.

LM a Wire on which the Plate EF slips up and down, parallel to the Cane of the *Thermometer* CD.

K, any Point at which the Spirit stands at the time of observation; suppose at 38 on the Spirit-*Thermometer*; Slide the Plate EF 'till the Hand G stand at 38 on the Air-*Thermometer*, and if the Liquor therein stand at 38 likewise, then is the pressure of the Air the same as at the time of Graduation, *viz.* 29, 5; but if it stand higher, as at 30, at I; then is the pressure of the Air greater; and the division on the sliding Plate against the Liquor, shews the present height of the *Mercury* to be twenty nine Inches seven Tenths. And this may suffice as to the manner of using it.

I had one of these Barometers with me in my late Southern Voyage, and it never failed to prognostick and give early notice of all the bad Weather we had, so that I depended thereon, and made provision accordingly; and from my own experience I conclude, that a more useful contrivance hath not for this long time been offered for the benefit of Navigation.

These

Digitized by Google

These Instruments are made according to the Direction of Dr. *Hook*, by Mr. *Henry Hunt*, Operator to the Royal Society, who will furnish any Gentlemen with them, and give them directions how to use them.

Digitized by Google

A Discourse concerning the Proportional Heat of the Sun in all Latitudes, with the Method of collecting the same, as it was read before the Royal Society in one of their late Meetings. By E. Halley.

THere having lately arisen some Discourse about that part of the Heat of Weather, simply produced by the Action of the Sun; and I having affirmed, that if that were considered, as the only Cause of the Heat of the Weather, I saw no reason, but that under the Pole the solstitial Day ought to be as hot as it is under the Æquinoctial, when the Sun comes vertical, or over the Zenith: For this reason, that for all the 24 Hours of that Day under the Pole, the Sun's Beams are inclined to the Horizon, with an Angle of $23\frac{1}{2}$ Degrees; and under the Æquinoctial, tho' he come vertical, yet he shines no more than 12 Hours, and is again 12 ~~Hours absent; and that for 3 Hours 6 Min.~~ of that 12 Hours, he is not so much elevated as under the Pole; so that he is not 9 of the whole 24 higher than 'tis there, and is 15 Hours lower. Now the simple Action of the Sun is, as all other Impulses or Strokes, more

or

Digitized by Google

or less forceable, according to the *Sinus* of the Angle of Incidence, or to the Perpendicular let fall on the Plain, whence the vertical Ray (being that of the greatest Heat) being put *Radius*, the force of the Sun on the Horizontal Surface of the Earth will be to that, as the *Sinus* of the Sun's Altitude at any other time. This being allowed for true, it will then follow, that the time of the continuance of the Sun's shining being taken for a *Basis*, and the *Sines* of the Sun's Altitudes erected thereon as Perpendiculars, and a Curve drawn through the Extreamities of those Perpendiculars, the *Area* comprehended shall be proportionate to the Collection of the Heat of all the Beams of the Sun in that space of time. Hence it will follow, that under the Pole the Collection of all the Heat of a tropical Day, is proportionate to a Rectangle of the *Sine* of $23\frac{1}{2}$ *gr.* into 24 Hours or the Circumference of a Circle; that is, the *Sine* of $23\frac{1}{2}$ *gr.* being nearly 4 Tenths of *Radius*; as $\frac{8}{10}$ into 12 Hours. Or the Polar Heat is equal to that of the Sun containing 12 Hours above the Horizon, at 53 *gr.* height, than which the Sun is not 5 Hours more elevated under the Æquinoctial.

But that this Matter may the better be understood, I have exemplied it by a Scheme (*Tab.4.Fig.2.*) wherein the *Area Z G H H*, is equal to the *Area* of all the *Sines* of the Sun's Altitude under the Æquinoctial, erected on the respective Hours from Sun-rise to the Zenith; and the *Area* ☌ *H H* ☌ is in the same portion to the Heat of the same 6 Hours under the Pole on the Tropical Day; and ☉

Digitized by Google

H H Q, is proportional to the collected Heat of 12 Hours, or half a Day under the Pole, which ſpace ⊙ *H H Q* is viſibly greater than the other *Area H Z G H*, by as much as the *Area H G Q* is greater than the *Area Z G* ⊙; which, that it is ſo, is viſible to ſight, by a great exceſs; and ſo much in proportion does the Heat of the 24 Hours Sun ſhine under the Pole, exceed that of the twelve Hours under the Æquinoctial: Whence, *Cæteris paribus*, it is reaſonable to conclude, that were the Sun perpetually under the Tropick, the Pole would be at leaſt as warm, as it is now under the Line itſelf.

But whereas the Nature of Heat is to remain in the Subject, after the Cauſe that heated is removed, and particularly in the Air; under the Æquinoctial, the twelve Hours abſence of the Sun does very little ſtill the Motion impreſſed by the paſt Action of his Rays, wherein Heat conſiſts, before he ariſe again: But under the Pole the long abſence of the ⊙ for 6 Months, wherein the extreamity of Cold does obtain, has ſo chilled the Air, that it is as it were frozen, and cannot, before the Sun has got far towards it, be any way ſenſible of his preſence, his Beams being obſtructed by thick Clouds, and perpetual Foggs and Miſts, and by that Atmoſphere of Cold, as the late Honourable Mr. *Boyl* was pleaſed to term it, proceeding from the everlaſting Ice, which in immenſe Quantities does chill the Neighbouring Air, and which the too ſoon retreat of the Sun leaves unthawed, to encreaſe again, during the long Winter that follows this ſhort interval of Summer. But the differing

Digitized by Google

differing Degrees of Heat and Cold in differing Places, depend in great measure upon the Accidents of the Neighbourhood of high Mountains, whose height exceedingly chills the Air brought by the Winds over them; and of the Nature of the Soil, which variously retains the Heat, particularly the Sandy, which in *Africa*, *Arabia*, and generally where such Sandy Deserts are found, do make the Heat of the Summer incredible to those that have not felt it.

In the prosecution of this first Thought, I have solved the Problem generally, *viz.* to give the proportional Degree of Heat, or the sum of all the *Sines* of the Sun's Altitude, while he is above the Horizon in any oblique Sphere, by reducing it to the finding of the Curve Surface of a Cylindrick Hoof, or of a given part thereof.

Now this Problem is not of that difficulty as appears at first sight, for in *Tab. 4. Fig.* 3. let the Cylinder ABCD be cut obliquely with the Ellipse BKDI, and by the Center thereof H, describe the Circle IKLM; I say, the Curve Surface IKLB is equal to the Rectangle of IK and BL, or of HK and 2 BL or BC: And if there be supposed another Circle, as NQPO, cutting the said Ellipse in the Points P, Q; draw PS, QR, parallel to the Cylinders Axe, till they meet with the aforesaid Circle IKLM in the Points R, S, and draw the Lines RTS, QVP bisected in T and V. I say again, that the Curve Surface RMSQDP is equal to the Rectangle of BL or MD and RS, or of 2 BL or AD and ST or VP; and the Curve Surface QNPD is equal to RS × MD---the Arch

Digitized by Google

RMS x SP, or the Arch MS x 2 SP: Or it is equal to the Surface RMSQDP, substracting the Surface RMSQNP. So likewise the Curve Surface QBPO is equal to the sum of the Surface RMSQDP or RS x MD, and of the Surface RLSQOP, or the Arch LS x 2 SP.

This is the most easily demonstrated from the Consideration, That the Cylindrick Surface IKLB is to the inscribed Spherical Surface IKLE, either in the whole, or in its Analogous Parts, as the tangent BL is to the Arch EL, and from the Demonstrations of *Archimedes de Sphæra & Cylindro, Lib.* 1. *Prop.* xxx. and xxxvii. xxxiix. which I shall not repeat here, but leave the Reader the pleasure of examining it himself; nor will it be amiss to consult Dr. *Barrow*'s Learned Lectures on that Book, Published at *London*, *Anno.* 1684, *viz. Probl.* ix. and the Corollaries thereof.

Now to reduce our Case of the Sum of all the *Sines* of the Sun's Altitude in a given Declination and Latitude to the aforesaid Problem, let us consider *(Tab.* 4. *Fig.* 4.*)* which is the *Analemma* projected on the Plain of the *Meridian*, Z the Zenith, P the Pole, HH the Horizon, æ æ the Æquinoctial, ♋ ♋, ♑ ♑ the two Tropicks, ♋ I the *Sine* of the Meridian Altitude in ♋; and equal thereto, but perpendicular to the Tropick, erect ♋ 1, and draw the Line T 1 intersecting the Horizon in T, and the Hour Circle of 6, in the Point 4, and 6 4 shall be equal to 6R, or to the *Sine* of the Altitude at 6: And the like for any other Point in the Tropick, erecting a Perpendicular thereat, terminated by the Line T 1: Through the Point 4 draw the Line 4 5 7 parallel

allel to the Tropick, and representing a Circle equal thereto; then shall the Tropick ♋ ♋ in *Fig.* 4. answer to the Circle NOPQ, in *Fig.* 3. the Circle 457 shall answer the Circle IKLM, T 4 1 shall answer to the Elliptick Segment QIBKP, 6 R or 6 4 shall answer to SP, and 5 1 to BL, and the Arch ♋ T, to the Arch LS, being the semidiurnal Arch in that Latitude and Declination; the *Sine* whereof, tho' not expressible in *Fig.* 4. must be conceived as Analogous to the Line TS or UP in *Fig.* 3.

The Relation between these two Figures being well understood, it will follow from what precedes, That, *the sum of the* Sines *of the Meridian Altitudes of the Sun in the two Tropicks, (and the like for any two opposite Parallels) being multiplied by the* Sine *of the semidiurnal Arch, will give an* Area *Analogous to the Curve Surface RMSQDP; and thereto adding in Summer, or substracting in Winter, the Product of the length of the semidiurnal Arch, (taken according to* Van Ceulen's *Numbers) into the difference of the above-said* Sines *of the Meridian Altitude: The sum in one case and difference in another shall be as the Aggregate of all the* Sines *of the Sun's Altitude, during his appearance above the Horizon; and consequently of all his Heat and Action on the Plain of the Horizon in the proposed Day.* And this may also be extended to the parts of the same Day; for if the aforesaid Sum of the *Sines* of the Meridian Altitudes, be multiplied by half the sum of the *Sines* of the Sun's Horary distance from Noon, when the Times are before and after Noon; or by half their difference, when both are on the same side of

Digitized by Google

the Meridian; and thereto in Summer, or therefrom in Winter, be added or substracted the Product of half the Arch answerable to the proposed interval of Time, into the difference of the *Sines* of Meridian Altitudes, the sum in one case and difference in the other, shall be proportional to all the Action of the Sun during that space of time.

I fore-see it will be Objected, that I take the *Radius* of my Circle on which I erect my Perpendiculars always the same, whereas the Parallels of Declination are unequal; but to this I answer, that our said Circular Bases ought not to be Anologous to the Parallels, but to the Times of Revolution, which are equal in all of them.

It may perhaps be useful to give an Example of the Computation of this Rule, which may seem difficult to some. Let the Solstitial Heat, in ♋ and ♑ be required at *London*, *Lat.* 51°. 32.

38o-2'8	*Co-Lat.*		*Diff. Ascen.*	330:-1'1.
23-30	*Decl.* ☉		*Arc. Semidi. æstiv.*	123-11.
61-58	*Sinus* =	,882674	*Arc. Semi. hyb.*	56-49. *S.* ,838923
14-58	*Sinus* =	,258257	*Arc. æstiv. mens.*	2,149955
	Summa	1,140931	*Arc. hyb. mensura*	991683
	Diff.	,624417		

Then 1, 140931 in ,836923+, 624417 in 2, 149955=2, 29734. And 1, 140931 in 836929 ---,624417 in ,991638= 33895.

So that 2, 29734 will be as the Tropical Summers Days Heat, and 0, 33895 as the Action of the Sun in the Day of the Winter Solstice.

After

Digitized by Google

After this manner I computed the following Table for every tenth Degree of Latitude, to the Æquinoctial and Tropical Sun, by which an Estimate may be made of the intermediate Degrees.

Lat.	Sun in ♈ ♎	Sun in ♋	Sun in ♑
0	20000	18341	18341
10	19696	20290	15834
20	18794	21737	13166
30	17321	22651	10124
40	15321	23048	6944
50	12855	22991	3798
60	10000	22773	1075
70	6840	23543	000
80	3473	24673	000
90	0000	25055	000

Those that desire more of the Nature of this Problem, as to the Geometry thereof, would do well to compare the XIII. *Prop. Cap.* V. of the Learned Treatise, *De Calculo Centri Gravitatis*, by the Reverend Dr. *Wallis*, Published *Anno.* 1670.

From this Rule there follow several Corollaries worth Note: As I. That the Æquinoctial Heat, when the Sun comes Vertical, is as twice the Square of *Radius*, which may be proposed as a Standard to compare with in all other Cases. II. That under the Æquinoctial, the Heat is as the *Sine* of the Sun's Declination. III, That in the Frigid Zones when the Sun sets not, the Heat is as the Circumfer-

Digitized by Google

ence of a Circle into the *Sine* of the Altitude at 6. And consequently, that in the same Latitude these Aggregates of Warmth, are as the *Sines* of the Sun's Declinations; and in the same Declination of *Sol*, they are as the *Sines* of the Lat., and generally they are as the *Sines* of the Lat. into the *Sines* of Declination. IV. That the Æquinoctial Days Heat is every where as the Co-sine of the Latitude. V. In all places where the Sun sets, the difference between the Summer and Winter Heats, when the Declinations are contrary, is equal to a Circle into the *Sine* of the Altitude at six in the Summer Parallel, and consequently those differences are as the *Sines* of Latitude into, or multiplied by the *Sines* of Declination. VI. From the Table I have added, it appears, that the Tropical Sun under the Æquinoctial, has, of all others, the least Force. Under the Pole it is greater than any other Days Heat whatsoever, being to that of the Æquinoctial as 5 to 4.

From the Table and these Coralleries may a general *Indea* be conceived of the sum of all the Actions of the Sun in the whole Year, and that part of the Heat that arises simply from the Presence of the Sun be brought to a Geometrical Certainty: And if the like could be performed for Cold; which is something else than the bare Absence of the Sun, as appears by many Instances, we might hope to bring what relates to this part of *Meteorology* to a perfect Theory.

Con-

Digitized by Google

Concerning the Distance of the fix'd Stars. By the Honourable Francis Roberts, *Esq; S. R. S.*

THE Ancient Astronomers, who had no other way of computing the Distances of the Heavenly Bodies, but by their Parallax to the Semi-diameter of the Earth; and being never able to discover any in the fix'd Stars, did from thence rightly enough infer, that their Distance was very great, and much exceeding that of the Planets, but could go no farther otherwise than by uncertain guess.

Since the *Pythagorean* System of the World has been revived by *Copernicus*, (and now by all Mathematicians accepted for the true one) there seemed ground to imagine that the Diameter of the Earth's Annual Course (which, according to our best Astronomers, is at least 40000 times bigger than the Semi-diameter of the Earth) might give a sensible Parallax to the fix'd Stars, tho' the other could not, and thereby determine their Distance more precisely.

But though we have a Foundation to build on so vastly exceeding that of the Ancients, there are some Considerations may make us suspect that even this is not large enough for our purpose.

Monsieur

Digitized by Google

Monsieur *Hugens* (who is very exact in his Astronomical Observations) tells us, he could never discover any visible Magnitude in the fix'd Stars, though he used Glasses which magnified the apparent Diameter above 100 times.

Now, since in all likelyhood the fix'd Stars are Suns, (perhaps of a different Magnitude) we may as a reasonable *Medium* presume they are generally about the bigness of our Sun.

Let us then (for Example) suppose the Dog-Star to be so. The Distance from us to the Sun being about 100 times the Sun's Diameter (as is demonstrable from the Sun's Diameter being 32 minutes) it is evident, that the Angle under which the Dog-Star is seen in Mr. *Hugens*'s Telescope, must be near the same with the Angle of its Parallax to the Sun's Distance, or Semi-diameter of the Earth's Annual Course; so that the Parallax to the whole Diameter, can be but double such a quantity, as even to Mr. *Hugens*'s nice Observation is altogether insensible.

The Distance therefore of the fixt Stars seems hardly within the reach of any of our Methods to determine; but from what has been laid down, we may draw some Conclusions that will much illustrate the prodigious vastness of it.

1. That the Diameter of the Earth's Annual Orb (which contains at least 160 millions of miles) is but as a Point in comparison of it; at least it must be above 6000 times the Distance of the Sun: For if a Star should appear through the aforesaid Telescope half a minute

minute broad (which is a pretty sensible Magnitude) the true apparent Diameter would not exceed 18 3d minutes, which is less than the 6000th part of the apparent Diameter of the Sun, and consequently the Sun's Distance not the 6000th part of the Distance of the Star.

2. That could we advance towards the Stars 99 Parts of the whole Distance, and have only $\frac{1}{100}$ Part remaining, the Stars would appear little bigger to us than they do here; for they would shew no otherwise than they do through a Telescope, which magnifies an Hundred-fold.

3. That at least Nine Parts in Ten of the Space between us and the fixed Stars, can receive no greater Light from the Sun, or any of the Stars, than what we have from the Stars in a clear Night.

4. That Light takes up more time in travelling from the Stars to us, than we in making a *West-India* Voyage (which is ordinarily performed in six Weeks.) That a Sound would not arrive to us from thence in 50000 Years, nor a Cannon-bullet in a much longer time. This is easily computed, by allowing (according to Mr. *Newton*) Ten minutes for the Journey of Light from the Sun hither, and that a Sound moves about 1300 Foot in a Second.

The

The Famous Mr. Isaac Newton's *Theory of the* Moon.

THIS *Theory* which hath been long expected by all the true Lovers of *Astronomy*, was communicated from Mr. *Newton*, to Dr. *Gregory Astron.* Professor at *Oxford*, and by him published in his *Astron. Elem. Philos.* and *Geomet.* p. 336. From whence, as it was lately translated into *English*, I thought fit to insert it here.

By this Theory, what by all Astronomers was thought most difficult and almost impossible to be done, the Excellent Mr. *Newton* hath now effected; *viz.* to determine the Moon's Place even in her Quadratures, and all other Parts of her Orbit, besides the Syzygys, so accurately by Calculation, that the Difference between that and her true Place in the Heavens, shall scarce be two minutes, and is usually so small, that it may well enough be reckon'd only as a Defect in the Observation. And this Mr. *Newton* experienced by comparing it with very many Places of the Moon, observ'd by Mr. *Flamsteed*, and communicated to him.

The Royal Observatory at *Greenwich*, is to the West of the Meridian of *Paris*, 2 deg. 19 min. Of *Urainburgh*, 12 deg. 51 min. 30 seconds. And of *Gedanum*, 18 deg. 48 minutes.

The

Digitized by Google

The mean Motions of the Sun and Moon, accounted from the Vernal Æquinox at the Meridian of *Greenwich*, I make to be as followeth.

The last Day of *December* 1680, at Noon, (*Old Stile*) the mean Motion of the Sun was 9 Sign, 20 deg. 34 min. 46 seconds. Of the Sun's Apogeum, was 3 S. 7 deg. 23 min. 30 sec.

The mean Motion of the Moon at that time, was 6 S. 1 deg. 35 min. 45 seconds. And of her Apogee, 8 S. 4 deg. 28 min. 5 seconds. Of the ascending Node of the Moon's Orbit, 5 S. 24 deg. 14 min. 35 seconds, *&c.*

And on the last Day of *December*, 1700. at Noon, the mean Motion of the Sun was 9 S. 20 deg. 43 min. 50 seconds. Of the Sun's Apogee, 3 S. 7 deg. 44 min. 30 seconds. The mean Motion of the Moon was 10 S. 15 deg. 19 min. 50 seconds. Of the Moon's Apogee, 11 S. 8 deg. 18 min. 20 seconds. And of her ascending Node, 4 S. 27 deg. 24 min. 20 seconds. For in 20 *Julian* Years, or 7305 Days, the Sun's Motion is 20 Revolut. 0 S. 0 deg. 9 min. 4 seconds. And the Motion of the Sun's Apogee, 21 min. 0 seconds.

The Motion of the Moon in the same time, is 247 Revolut. 4 S. 13 deg. 34 min. 5 seconds. And the Motion of the Lunar Apogee, is 2 Revolut. 3 S. 3 deg. 50 min. 15 seconds. And the Motion of her Node, 1 Revolut. 0 S. 26 deg. 50 min. 15 seconds.

All which Motions are accounted from the Vernal Æquinox: Wherefore if from them there be subtracted the Recession or Motion of the Æquinoctial Point, *in Antecedentia*, during that space, which is 16 min. 0 sec. there will

Digitized by Google

will remain the Motions in reference to the fix'd Stars in 20 *Julian* Years; *viz.* the Sun's 19 Revol. 11 S. 29 deg. 52 min. 24 seconds. Of his Apogee, 4 min. 20 seconds. And the Moon's 247 Revol. 4 S. 13 deg. 17 min. 25 seconds. Of her Apogee, 2 Revol. 3 S. 3 deg. 33 min. 35 seconds. And of the Node of the Moon, 1 Revol. 0 S. 27 deg. 6 min. 55 seconds.

According to this Computation, the *Tropical Year* is 365 Days, 5 Hours, 48 Minutes, 57 Seconds. And the *Sydereal Year* is 365 Days, 6 Hours, 9 Minutes, 14 Seconds.

These mean Motions of the Luminaries are affected with various Inequalities: Of which,

1. There are the Annual Equations of the aforesaid mean Motions of the Sun and Moon, and of the Apogee and Node of the Moon.

The Annual Equation of the mean Motion of the Sun, depends on the Eccentricity of the Earth's Orbit round the Sun, which is $16\frac{11}{12}$ of such Parts, as that the Earth's mean Distance from the Sun shall be 1000: Whence 'tis called the *Equation of the Centre*; and is, when greatest, 1 deg. 56 min. 20 seconds.

The greatest Annual Equation of the Moon's mean Motion, is 11 deg. 49 seconds; of her Apogee, 20 min. and of her Node, 9 minutes, 30 seconds.

And these four Annual Equations are always mutually proportional one to another: Wherefore when any of them is at the greatest, the other three will also be greatest; and when any one lessens, the other

ther three will also be diminished in the same *Ratio*.

The Annual Equation of the Sun's Centre being given, the three other correspending Annual Equations will be also given; and therefore a Table of that will serve for all. For if the Annual Equation of the Sun's Centre be taken from thence, for any Time, and be called P, and let $\frac{1}{1}$. P = Q, Q + $\frac{1}{60}$ Q = R, $\frac{1}{8}$ P = D, D + $\frac{1}{30}$ D = E, and D - $\frac{1}{30}$ D = 2 F; then shall the Annual Equation of the Moon's mean Motion for that time be R, that of the Apogee of the Moon will be E, and that of the Node F.

Only observe here, That if the Equation of the Sun's Centre be required to be added; then the Equation of the Moon's mean Motion must be subtracted, that of her Apogee must be added, and that of the Node subducted. And on the contrary, if the Equation of the Sun's Centre were to be subducted, the Moon's Equation must be added, the Equation of her Apogee subducted, and that of her Node added.

There is also an *Equation of the Moon's mean Motion*, depending on the Situation of her Apogee, in respect of the Sun; which is greatest when the Moon's Apogee is in an Octant with the Sun, and is nothing at all when it is in the Quadratures or Syzygys. This Equation, when greatest, and the Sun in *Perigæo*, is 3 min. 56 seconds. But if the Sun be in *Apogæo*, it will never be above 3 minutes 34 seconds. At other Distances of the Sun from the Earth, this Equation, when greatest, is reciprocally as the Cube of such Distance. But

when

when the Moon's Apogee is any where but in the *Octants*, this Equation grows less, and is mostly at the same distance between the Earth and Sun, as the Sine of the double Distance of the Moon's Apogee, from the next Quadrature or Syzygy, to the Radius.

This is to be added to the Moon's Motion, while her Apogee passes from a Quadrature with the Sun to a Syzygy; but this is to be subtracted from it, while the Apogee moves from the Syzygy to the Quadrature.

There is moreover another *Equation of the Moon's Motion*, which depends on the Aspect of the Nodes of the Moon's Orbit with the Sun: And this is greatest, when her Nodes are in *Octants* to the Sun, and vanishes quite, when they come to their Quadratures or Syzygys. This Equation is proportional to the Sine of the double Distance of the Node from the next Syzygy, or Quadrature; and at greatest, is but 47 seconds. This must be added to the Moon's mean Motion, while the Nodes are passing from their Syzygys with the Sun, to their Quadratures with him; but subtracted while they pass from the Quadratures to the Syzygys.

From the Sun's true Place, take the equated mean Motion of the Lunar Apogee, as was above shew'd, the Remainder will be the Annual Argument of the said Apogee. From whence the *Eccentricity of the Moon*, and the *second Equation* of her Apogee may be compar'd after the manner following (*which takes place also in the Computation of any other intermediate Equations.*

Let

Tab. 3. Fig. 6. Let T repreſent the Earth, T S a Right Line joining the Earth and Sun, T A C B a Right Line drawn from the Earth to the middle or mean Place of the Moon's Apogee, equated, as above: Let the Angle S T A be the Annual Argument of the aforeſaid Apogee, T A the leaſt Eccentricity of the Moon's Orbit, T B the greateſt. Biſſect A B in G; and on the Centre C, with the Diſtance A C deſcribe a Circle A F B, and make the Angle B C F = to the double of the Annual Argument. Draw the Right Line T F, that ſhall be the Eccentricity of the Moon's Orbit; and the Angle B T F, is the ſecond Equation of the Moon's Apogee required.

In order to whoſe Determination, let the mean Diſtance of the Earth from the Moon, or the Semi-diameter of the Moon's Orbit, be 1000000; then ſhall its greateſt Eccentricity T B be 66782 ſuch Parts; and the leaſt T A, 43319. So that the greateſt Equation of the Orbit, *viz.* when the Apogee is in the Syzygys, will be 7 deg. 39 min. 30 ſeconds, or perhaps 7 deg. 40 min. (for I ſuſpect there will be ſome Alteration, according to the Poſition of the Apogee in *Cancer* or *Capricorn.*) But when it is Quadrate to the Sun, the greateſt Equation aforeſaid will be 4 deg. 57 min. 56 ſeconds; and the greateſt Equation of the Apogee, 12 deg. 15 min. 4 ſeconds.

Having from theſe Principles made a Table of the Equation of the Moon's Apogee, and of the Eccentricities of her Orbit to each degree of the Annual Argument, from whence the Eccentricity T F, and the Angle B T F (*viz.* the ſecond and principal Equation of

Digitized by Google

the Apogee) may eaſily be had for any Time required; let the Equation thus found be added to the firſt Equated Place of the Moon's Apogee, if the Annual Argument be leſs than 90 degrees, or greater than 180 degrees, and leſs than 270; otherwiſe it muſt be ſubducted from it; and the Summ or Difference ſhall be the Place of the Lunar Apogee ſecondarily equated; which being taken from the Moon's Place equated a third time, ſhall leave the mean Anomaly of the Moon correſponding to any given Time. Moreover, from this mean Anomaly of the Moon, and the before-found Eccentricity of her Orbit, may be found (by means of a Table of Equations of the Moons Centre made to every degree of the mean Anomaly, and ſome Eccentricities, (*viz.* 45000, 50000, 55000, 60000, and 65000) the *Proſtaphæreſis*, or Equation of the Moon's Centre, as in the common way: And this being taken from the former Semi-circle of the middle Anomaly, and added in the latter to the Moon's Place thus thrice equated, will produce the Place of the Moon a fourth time equated.

The greateſt Variation of the Moon (*viz.* that which happens when the Moon is in an Octant with the Sun) is nearly, reciprocally as the Cube of the Diſtance of the Sun from the Earth. Let that be taken 37 min. 25 ſeconds, when the Sun is *in Perigæo*, and 33 min. 40 ſeconds, when he is *in Apogæo*: And let the Differences of this Variation in the Octants be made reciprocally, as the Cubes of the Diſtances of the Sun from the Earth; and ſo let a Table be made of the aforeſaid Variation

Digitized by Google

tion of the Moon in her Octants (or its Logarithms) to every Tenth, Sixth, or Fifth Degree of the mean Anomaly: And for the Variation out of the Octants, make, as Radius to the Sine of the double Distance of the Moon from the next Syzygy, or Quadrature : : so let the afore-found Variation in the Octant be to the Variation congruous to any other Aspect; and this added to the Moon's Place before found in the first and third Quadrant (accounting from the Sun) or subducted from it in the second and fourth, will give the Moon's Place equated a fifth time.

Again, as Radius to the Sine of the Summ of the Distances of the Moon from the Sun, and of her Apogee from the Sun's Apogee (or the Sine of the Excess of that Summ above 360 deg.) : : so is 2 min. 10 seconds, to a sixth Equation of the Moon's Place, which must be subtracted, if the aforesaid Summ or Excess be less than a Semi-circle; but added, if it be greater. Let it be made also, as Radius to the Sine of the Moon's distance from the Sun : : so 2 deg. 20 secants, to a seventh Equation; which when the Moon's Light is increasing, add; but when decreasing, subtract; and the Moon's Place will be equated a seventh time, and this is her Place *in her proper Orbit*.

Not here, the Equation thus produced by the mean Quantity 2 degrees, 20 seconds, is not always of the same magnitude; but is increased and diminished, according to the Position of the Lunar Apogee. For if the Moon's Apogee be in Conjunction with the

Digitized by Google

Sun's, the aforesaid Equation is about 54 seconds greater: But when the Apogees are in opposition, 'tis about as much less; and it librates between its greatest Quantity 3 minutes, 14 seconds, and its least, 1 minute, 26 seconds. And this is, when the Lunar Apogee is in Conjunction, or Opposition with the Sun's: But in the Quadratures, the aforesaid Equation is to be lessen'd about 50 seconds, or one minute, when the Apogees of the Sun and Moon are in Conjunction; but if they are in Opposition, for want of a sufficient number of Observations, I cannot determine, whether it is to be lessen'd or increas'd. And even as to the Argument or Decrement of the Equation, 2 minutes, 20 seconds, above mentioned, I dare determine nothing certain, for the same Reason, *viz.* the want of Observation accurately made.

If the sixth and seventh Equations are augmented or diminished in a reciprocal *Ratio* of the distance of the Moon from the Earth; *i. e.* in a direct *Ratio* of the Moon's Horizontal Parallax, they will become more accurate: And this may be readily done, if Tables are first made to each minute of the said Parallax, and to every sixth or fifth degree of the Argument of the sixth Equation for the Sixth, as of the distance of the Moon from the Sun, for the Seventh Equation.

From the Sun's Place, take the mean motion of the Moon's ascending Node, equated as above; the Remainder shall be the Annual Argument of the Node, whence its second Equation may be computed after the following manner in the preceding Figure.

Let

Digitized by Google

Let T, as before, represent the Earth; TS a Right Line, conjoining the Earth and Sun: Let also the Line T A C B, be drawn to the Place of the ascending Node of the Moon, as above equated; and let S T A be the Annual Argument of the Node. Take T A from a Scale, and let it be to A B :: as 56 to 3, or as 11 $\frac{2}{3}$ to 1. Then bisect B A in C, and on C as a Centre, with the Distance C A, describe a Circle as A F B, and make the Angle B C F, equal to double the Annual Argument of the Node before-found: So shall the Angle B T F, be the second Equation of the ascending Node; which must be added, when the Node is passing from the Quadrature to a Syzygy with the Sun; and subducted, when the Node moves from a Syzygy towards a Quadrature. By which means, the true Place of the Node of the Lunar Orbit will be gained: Whence from Tables made after the common way, the *Moon's Latitude, and the Reduction of her Orbit to the Ecliptick*, may be computed, supposing the Inclination of the Moon's Orbit to the Ecliptick, to be 4 deg. 59 min. 35 seconds, when the Nodes are in Quadrature with the Sun; and 5 deg. 17 min. 20 seconds, when they are in the Syzygys.

And from the Longitude and Latitude thus found, and the given Obliquity of the Ecliptick, 23 degrees, 29 minutes, to the Right Ascension and Declination of the Moon will be found.

The Horizontal Parallax of the Moon, when she is in the Syzygys, at a mean distance from the Earth, I make to be 57 min. 30 seconds; and her Horary Motion, 33 min. 32

Digitized by Google

seconds, 32 thirds; and her apparent Diameter 31 min. 30 seconds. But in her Quadratures at a mean Distance from the Earth, I make the Horizontal Parallax of the Moon to be 59 min. 40 seconds, her Horary Motion 32 min. 12 seconds, 2 thirds, and her apparent Diameter, 31 min. 3 seconds. The Moon in an Octant to the Sun, and at a mean distance, hath her Centre distant from the Centre of the Earth about 60 $\frac{1}{9}$ of the Earth's Semi-diameters.

The Sun's Horizontal Parallax I make to be 10 seconds, and its apparent Diameter at a mean distance from the Earth, I make 32 minutes, 15 seconds.

The Atmosphere of the Earth, by dispersing and refracting the Sun's Light, casts a Shadow, as if it were an Opake Body, at least to the height of 40 or 50 Gebgraphical Miles (by a Geographical Mile, I mean the sixtieth part of a Degree of a great Circle, on the Earth's Surface.) This Shadow falling upon the Moon in a Lunar Eclipse, makes the Earth's Shadow be the larger or broader. And to each Mile of the Earth's Atmosphere, is correspondent a Second in the Moon's Disk; so that the Semi-diameter of the Earth's Shadow projected upon the Disk of the Moon, is to be increased about 50 seconds: Or, which is all one, in a Lunar Eclipse, the Horizontal Parallax of the Moon is to be increased in the Ratio of about 70 to 69.

This far the Theory of this incomparable Mathematician. And if we had many Places of the Moon accurately observed, especially about her Quadratures, and these well compared

Digitized by Google

Digitized by Google

Digitized by Google

pared with her Places, at the ſame time calculated according to this Theory; it would then appear, whether there yet remain any other ſenſible Equations, which when accounted for, might ſerve to improve and enlarge this Theory.

Digitized by Google

An Estimate of the Degrees of the Mortality *of Mankind, drawn from curious* Tables *of the* Births *and* Funerals *at the City of* Breslaw; *with an Attempt to ascertain the Price of* Annuities *upon* Lives. *By Mr.* E. Halley, *R.S.S.*

THE Contemplation of the *Mortality* of *Mankind*, has besides the *Moral*, its *Physical* and *Political* Uses, both which have been some Years since most judiciously considered by the curious Sir *William Petty*, in his *Natural* and *Political* Observations on the Bills of *Mortality* of *London*, owned by Captain *John Graunt*: And since in a like Treatise on the Bills of *Mortality* of *Dublin*. But the Deduction from those Bills of *Mortality* seemed even to their Authors to be defective: First, In that the *Number* of the People was wanting. Secondly, That the *Ages* of the People dying was not to be had. And Lastly, That both *London* and *Dublin*, by reason of the great and casual Accession of *Strangers* who die therein, (as appeared in both, by the great Excess of the *Funerals* above the *Births*) rendred them incapable of being Standards for this purpose; which requires, if it were

Digitized by Google

were poſſible, that the People, we treat of, ſhould not at all be changed, but die where they were born, without any adventitious Increaſe from Abroad, or Decay by Migration elſewhere.

This *Defect* ſeems in a great meaſure to be ſatisfied by the late curious Tables of the Bills of *Mortality* at the City of *Breſlaw*, lately communicated to this Honourable Society by Mr. *Juſtell*, wherein both the Ages and Sexes of all that die are monthly delivered, and compared with the number of the *Births*, for Five Years laſt paſt, *viz.* 1687, 88, 89, 90, 91, ſeeming to be done with all the Exactneſs and Sincerity poſſible.

This City of *Breſlaw* is the Capital City of the Province of *Sileſia*; or, as the *Germans* call it, *Schleſia*, and is ſituated on the Weſtern Bank of the River *Oder*, anciently called *Viadrus*, near the Confines of *Germany* and *Poland*, and very nigh the Latitude of *London*. It is very far from the Sea, and as much a *Mediterranean* Place as can be deſired, whence the Confluence of Strangers is but ſmall, and the Manufacture of Linnen employs chiefly the poor People of the Place, as well as of the Country round about; whence comes that ſort of Linnen we uſually call your *Sclaſie Linnen*; which is the chief, if not the only Merchandize of the Place. For theſe Reaſons, the People of this City ſeem moſt proper for a *Standard*; and the rather, for that the *Births* do, a ſmall matter exceed the Funerals. The only thing wanting, is the Number of the whole People, which in ſome meaſure I have endeavour'd to ſupply, by the compariſon

Digitized by Google

parison of the *Mortality* of the People of all Ages, which I shall from the said Bills trace out with all the Accuracy possible.

It appears that in the Five Years mentioned, *viz.* from 87 to 91 inclusive, there were *born* 6193 Persons, and buried 5869; that is, born *per Annum* 1238, and *buried* 1174; whence an *Increase* of the People may be argued of 64 *per Annum*, or of about a 20th part, which may perhaps be balanced by the Levies for the *Emperor*'s Service in his Wars. But this being contingent, and the Births certain, I will suppose the People of *Breslaw* to to be increased by 1238 *Births* annually. Of these it appears by the same Tables, that 348 do die *yearly* in the *first Year* of their *Age*, and that but 890 do arrive at a full *Year's Age*; and likewise, that 198 do die in the *Five Years* between 1 and 6 compleat, taken at a *Medium*; so that but 692 of the Persons *born* do survive *Six* whole *Years*. From this *Age* the Infants being arrived at some degree of Firmness, grow less and less *Mortal*; and it appears, that of the whole People of *Breslaw* there die *yearly*, as in the following Table, wherein the upper Line shews the *Age*, and the next under it, the *Number* of Persons of that Age *dying yearly*.

Digitized by Google

7. 8 9. 14 18 . 21 . 27 . 28 . 35.
11. 11. 6. 5½. 2. 3½. 5 6 4½ 6½ 9 . 8. 7 .7.

36. 42. 45 39 54 . 55 . 56 . 63
8. 9½ 8 . 9. 7. 7. 10 11 . 9 . 9. 10. 12

70 71 . 72 77 81 84 . 90 91.
9½ 14 9. 11 9½ 6 .7 .3 .4 .2 . 1. 1. 1.

98 . 99 . 100.
0 . ½ . ½

And where no Figure is placed over, it is to be understood of those that die between the Ages of the precedent and consequent *Column.*

From this Table it is evident, that from the Age of 9 to about 25, there does not die above 6 *per Annum* of each Age, which is much about 1 *per Cent.* of those that are of those *Ages*: And whereas in the 14, 15, 16, 17 *Years*, there appear to die much fewer, as 2 and 3½; yet that seems rather to be attributed to Chance, as are the other Irregularities in the Series of Ages, which would rectifie themselves, were the number of Years much more considerable, as 20 instead of 5. And by our own Experience in *Christ-Church Hospital*, I am informed there die of the *Young Lads*, much about 1 *per Cent. per Annum*, they being of the aforesaid *Ages*. From 25 to 50, there seem to die from 7 to 8 and 9 *per Annum* of each Age; and after that to 70, they growing more *crasie*, though the number be much diminished, yet the *Mortality increases*, and there are found to die 10 or 11 of each Age *per Annum*: From thence

Digitized by Google

thence the number of the Living being grown very ſmall, they gradually decline till there be none left to *die*; as may be ſeen at one *View* in the Table.

From theſe Conſiderations I have formed the *adjoined Table*, whoſe Uſes are manifold, and give a more juſt *Idea* of the *State* and *Condition* of *Mankind*, than any thing yet extant that I know of. It exhibits the *Number* of *People* in the City of *Breſlaw* of all Ages, from the *Birth* to extreme *Old Age*, and thereby ſhews the Chances of *Mortality* at all *Ages*, and likewiſe how to make a certain Eſtimate of the Value of *Annuities* for *Lives*, which hitherto has been only done by an imaginary *Valuation*: Alſo the *Chances* that there are that a *Perſon* of any *Age* propoſed does live to any other *Age* given; with many more, as I ſhall hereafter ſhew. This *Table* does ſhew the *Number* of Perſons that are living in the *Age* current annexed thereto, as follows:

Age.

Digitized by Google

Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.
1	1000	8	680	15	628	22	586	29	539	36	481
2	855	9	670	16	622	23	579	30	531	37	472
3	798	10	661	17	616	24	573	31	523	38	463
4	760	11	653	18	610	25	567	32	515	39	454
5	732	12	646	19	604	26	560	33	507	40	445
6	710	13	640	20	598	27	553	34	499	41	436
7	692	14	634	21	592	28	546	35	490	42	427
Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	ſons. Per-	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.	Age. Curt.	Per-sons.
43	417	50	346	57	272	64	202	71	131	78	58
44	407	51	335	58	262	65	192	72	120	79	49
45	397	52	324	59	252	66	182	73	109	80	41
46	387	53	313	60	242	67	172	74	98	81	34
47	377	54	302	61	232	68	162	75	88	82	28
48	367	55	292	62	222	69	152	76	78	83	23
49	357	56	282	63	212	70	142	77	68	84	20

Thus

Age.	Perſons.
7	5547
14	4584
21	4270
28	3964
35	3604
42	3178
49	2709
56	2194
63	1694
70	1204
77	692
84	253
100	107
	34000

Sum Total.

Digitized by Google

Thus it appears, that the whole People of *Breslaw* does consist of 34000 *Souls*, being the Sum *Total* of the Persons of all Ages in the *Table*: The first use hereof is to shew the Proportion of *Men* able to bear *Arms* in any *Multitude*, which are those between 18 and 56, rather than 16 and 60; the one being generally too weak to bear the *Fatigues* of *War*, and the Weight of *Arms*; and the other too crasie and infirm from *Age*, notwithstanding particular Instances to the contrary. Under 18 from the *Table*, are found in this City 11997 Persons, and 3950 above 56, which together make 15947. So that the Residue to 34000 being 18053, are Persons between those *Ages*. At least one half thereof are Males, or 9027: So that the whole Force this City can raise of *Fencible Men*, as the *Scotch* call them, is about 9000, or $\frac{1}{4}$, or somewhat more than a quarter of the *Number* of *Souls*, which may perhaps pass for a Rule for all other places.

The *Second Use* of this *Table*, is, to shew the differing degrees of *Mortality*, or rather *Vitality* in all *Ages*; for if the number of Persons of any *Age* remaining after one Year, be divided by the difference between that and the number of the Age proposed, it shews the *odds* that there is, that a Person of that Age does not die in a *Year*. As for Instance, a Person of 25 *Years* of *Age* has the odds of 560 to 7, or 80 to 1, that he does not *die* in a *Year*: Because that of 567, living of 25 Years of Age, there do die no more than 7 in a *Year*, leaving 560 of 26 Years old.

So

Digitized by Google

So likewiſe for the *odds*, that any Perſon does not die before he attain any propoſed *Age*: Take the *number* of the remaining Perſons of the Age propoſed, and divide it by the difference between it and the number of thoſe of the *Age* of the Party propoſed; and that ſhews the *odds* there is between the Chances of the Party's living or dying. As for Inſtance; What is the *odds* that a Man of 40 lives 7 Years: Take the number of Perſons of 47 Years, which in the Table is 377, and ſubtract it from the number of Perſons of 40 Years, which is 445, and the *difference* is 68: Which ſhews that the *Perſons dying* in that 7 Years, are 68; and that it is 377 to 68, or $5\frac{1}{2}$ to 1, that a Man of 40 does live 7 Years. And the like for any other *number* of *Years*.

Uſe III. But if it be enquired at what number of *Years*, it is an even Lay that a Perſon of any Age ſhall die, this Table readily performs it: For if the *number* of Perſons *living* of the *Age* propoſed, be *halfed*, it will be found by the *Table* at what Year the ſaid *Number* is reduced to half by *Mortality*; and that is the Age, to which it is an even Wager, that a Perſon of the *Age* propoſed ſhall arrive before he *die*. As for Inſtance; A Perſon of 30 Years of Age is propoſed, the number of that Age is 531, the half thereof is 265, which number I find to be between 57 and 58 Years; ſo that a Man of 30 may reaſonably expect to live between 27 and 28 Years.

Uſe IV. By what has been ſaid, the *Price* of *Inſurance* upon Lives ought to be regulated, and the difference is diſcovered between the

Price

Digitized by Google

Price of inſuring the *Life* of a *Man* of 20 and 50. For Example; it being 100 to 1, that a Man of 20 dies not in a Year, and but 38 to 1, for a Man of 50 Years of Age.

Uſe V. On this depends the Valuation of *Annuities* upon *Lives*; for it is plain, that the *Purchaſer* ought to pay for only ſuch a part of the Value of the *Annuity*, as he has Chances that he is living; and this ought to be computed yearly, and the Sum of all thoſe yearly Values being added together, will amount to the Value of the *Annuity* for the *Life* of the Perſon propoſed. Now the preſent Value of Money payable after a Term of Years, at any given Rate of Intereſt, either may be had from Tables already computed; or almoſt as compendiouſly, by the Table of Logarithms: For the Arithmetical Complement of the Logarithm of Unity and its yearly Intereſt, (that is, of 1, 06 for Six *per Cent.* being 9, 974694.) being multiplied by the number of Years propoſed, gives the preſent Value of One Pound payable after the end of ſo many Years. Then by the foregoing Propoſition, it will be as the number of Perſons living after that Term of Years, to the number dead; ſo are the odds that any one Perſon is alive or dead. And by conſequence, as the Sum of both, or the number of Perſons living of the Age firſt propoſed, to the number remaining after ſo many Years, (both given by the Table) ſo the preſent Value of the yearly Sum payable after the Term propoſed, to the Sum which ought to be paid for the Chance the Perſon has to enjoy ſuch an Annuity after ſo many Years. And this being repeated for every

Digitized by Google

every Year of the Perſon's Life, the Sum of all the preſent Values of thoſe Chances is the true Value of the Annuity. This will without doubt appear to be a moſt laborious Calculation; but it being one of the principal Uſes of this Speculation, and having found ſome *Compendia* for the Work, I took the pains to compute the following Table, being the ſhort Reſult of a not ordinary number of Arithmetical Operations: It ſhews the Value of Annuities for every Fifth Year of Age, to the Seventieth, as follows.

Age	Years Pur.	Age	Years Pur.	Age	Years Pur.
1	10,28	25	12,27	50	9,21
5	13,40	30	11,72	55	8,54
10	13,44	35	11,12	60	7,60
15	13,33	40	10,57	65	6,54
20	12,78	45	9,91	70	5,32

This ſhews the great Advantage of putting Money into the preſent *Fund* lately granted to Their Majeſties, giving 14 *per Cent. per Annum*, or at the Rate of 7 Years Purchaſe for a Life; when young Lives, at the uſual Rate of Intereſt, are worth above 13 Years Purchaſe. It ſhews likewiſe the Advantage of young Lives over thoſe in Years; a Life of Ten Years being almoſt worth 13½ Years Purchaſe, whereas one of 36 is worth but 11.

Uſe V. Two Lives are likewiſe valuable by the ſame Rule; for the number of Chances of each ſingle Life, found in the Table, being multiplied together, become the Chances of the Two Lives. And after any certain

Digitized by Google

Term of Years, the Product of the two remaining Sums is the Chances that both the Persons are living. The Product of the two Differences, being the numbers of the Dead of both Ages, are the Chances that both the Persons are dead. And the two Products of the remaining Sums of the one Age multiplied by those dead of the other, shew the Chances that there are, that each Party survives the other; Whence is derived the Rule to estimate the Value of the Remainder of one Life after another. Now as the Product of the Two Numbers in the Table for the Two Ages proposed, is to the difference between that Product, and the Product of the two numbers of Persons deceased in any space of time; so is the Value of a Sum of Money to be paid after so much time, to the Value thereof under the Contingency of Mortality. And as the aforesaid Product of the two Numbers answering to the Ages proposed, to the Product of the Deceased of one Age multiplied by those remaining alive of the other; so the Value of a Sum of Money to be paid after any time proposed, to the Value of the Chances, that the one Party has that he survives the other, whose number of Deceased you made use of, in the second Term of the Proportion. This perhaps may be better understood, by putting N for the number of the younger Age, and n for that of the Elder; r, y the Deceased of both Ages respectively, and R, Y for the Remainders; and $R + r = N$ and $r + y = n$. Then shall $N n$ be the whole Number of Chances; $N n - r y$ be the Chances that one of the two Persons is

 living,

Digitized by Google

living, *Y y* the Chances that they are both dead; *R y* the Chances that the elder Person is dead and the younger living; and *r Y* the Chances, that the elder is living and the younger dead. Thus two Persons of 18 and 25 are proposed, and after 8 Years these Chances are required. The Numbers for 18 and 25, are 610 and 490; and there are 50 of the First Age dead in 8 Years, and 73 of the Elder Age. There are in all 610 x 490, or 298900 Chances; of these there are 50 x 73, or 3650, that they are both dead. And as 298900, to 298900 — 3650, or 295250: So is the present Value of a Sum of Money to be paid after 8 Years, to the present Value of a Sum to be paid, if either of the two live. And as 560 x 73, so are the Chances that the Elder is dead leaving the Younger; and as 417 x 50, so are the Chances that the Younger is dead, leaving the Elder. Wherefore as 610 x 490 to 560 x 73, so is the present Value of a Sum to be paid at 8 Years end, to the Sum to be paid for the Chance of the Younger's Survivance; and as 610 x 490 to 417 x 50, so is the same present Value to the Sum to be paid for the Chance of the Elder's Survivance.

This possibly may be yet better explained by expounding these Products by Rectangular Parallelograms, as in *Fig.* 7, wherein *A B* or *C D* represents the number of Persons of the younger Age, and *D E*, *B H* those remaining alive after a certain Term of Years; whence *C E* will answer the number of those dead in that time; So *A C*, *B D* may represent the number of the elder Age; *A F*, *B I* the Survi-

vors after the same Term; and CF, DI, those of that Age that are dead at that time. Then shall the whole Parallelogram $ABCD$ be Nn, or the Product of the two Numbers of Persons, representing such a number of Persons of the two Ages given; and by what was said before, after the Term proposed, the Rectangle HD shall be as the number of Persons of the younger Age that survive, and the Rectangle AE as the number of those that die. So likewise the Rectangles AI, FD shall be as the Numbers, living and dead, of the other Age. Hence the Rectangle HI shall be as an equal number of both Ages surviving. The Rectangle FE being the Product of the Deceased, or Yy, an equal number of both dead. The Rectangle GD or Ry, a number living of the younger Age, and dead of the elder: And the Rectangle AG or rY a number living of the elder Age, but dead of the younger. This being understood, it is obvious, that as the whole Rectangle AD or Nn is to the *Gnomon* $FABDEG$ or $Nn-Yy$, so is the whole number of Persons or Chances, to the number of Chances that one of the two Persons is living: And as AD or Nn is to FE or Yy, so are all the Chances, to the Chances that both are dead; whereby may be computed the Value of the Reversion after both Lives. And as AD to GD or Ry, so the whole number of Chances, to the Chances that the younger is living, and the other dead; whereby may be cast up what Value ought to be paid for the Reversion of one Life after another, as in the Case of providing for Clergy-mens Widows, and others, by such Reversions.

Digitized by Google

Reverſions. And as AD to AG, or r Y, ſo are all the Chances, to thoſe that the elder ſurvives the younger. I have been the more particular, and perhaps tedious, in this Matter, becauſe it is the Key to the Caſe of Three Lives, which of it ſelf would not have been ſo eaſie to comprehend.

VII. If Three Lives are propoſed, to find the Value of an Annuity during the continuance of any of thoſe three Lives; the Rule is, *As the Product of the continual Multiplication of the Three Numbers, in the Table, anſwering to the Ages propoſed, is to the difference of that Product, and of the Product of the Three Numbers of the Deceaſed of thoſe Ages, in any given Term of Years: So is the preſent Value of a Sum of Money, to be paid certainly after ſo many Years, to the preſent Value of the ſame Sum to be paid, provided one of thoſe Three Perſons be living at the Expiration of that Term.* Which Proportion being yearly repeated, the Sum of all thoſe preſent Values will be the Value of an Annuity granted for three ſuch Lives. But to explain this, together with all the Caſes of Survivance in Three Lives: Let N be the Number in the Table for the younger Age, n for the ſecond, and ν for the elder Age; let Y be thoſe dead of the younger Age in the Term propoſed, y thoſe dead of the ſecond Age, and υ thoſe of the elder Age; and let R be the Remainder of the younger Age, r that of the middle Age, and ϱ the Remainder of the elder Age. Then ſhall $R + Y$ be equal to N, $r + y$ to n, and $\varrho + \upsilon$ to ν, and the continual Product of the three Numbers $N n \nu$ ſhall be equal to the continual Product of

Digitized by Google

$R+\Upsilon \times r+y \times \varrho+v$, which being the whole Number of Chances for three Lives, is compounded of the eight Products following. (1) $R r \varrho$, which is the Number of Chances that all three of the Persons are living. (2) $r \varrho \Upsilon$, which is the Number of Chances that the two elder Persons are living, and the younger dead. (3) $R \varrho y$ the Number of Chances that the middle Age is dead, and the younger and elder living. (4) $R r v$ being the Chances that the two younger are living, and the elder dead. (5) $\varrho \Upsilon y$ the Chances that the two younger are dead, and the elder living. (6) $r \Upsilon v$ the Chances that the younger and elder are dead, and the middle Age living. (7) $R y v$, which are the Chances that the younger is living, and the two other dead. And Lastly and Eighthly, $\Upsilon y v$, which are the Chances that all three are dead. Which latter subtracted from the whole Number of Chances $N n \nu$, leaves $N n \nu - \Upsilon y v$ the Sum of all the other seven Products; in all of which one or more of the three Persons are surviving.

To make this yet more evident, I have added *Fig.* 8. wherein these eight several Products are at one view exhibited. Let the rectangled Parallelepipedon $ABCDEFGH$ be constituted of the sides AB, GH, &c. proportional to N the Number of the younger Age; AC, BD, &c. proportional to n; and AG, CE, &c. proportional to the Number of the elder, or ν. And the whole Parallelepipedon shall be as the Product $N n \nu$, or our whole Number of Chances. Let BP be as R, and AP as Υ; let CL be as r, and Ln as

Digitized by Google

as y; and GN as ϱ, and NA as v; and let the Plain $PRea$ be made parallel to the Plain $ACGE$; the Plain $NVbY$ parallel to $ABCD$, and the Plain $LXTQ$ parallel to the Plain $ABGH$. And our first Product $Rr\varrho$ shall be as the Solid $STWIFZeb$. The Second, or $r\varrho\Upsilon$ will be as the Solid $E\Upsilon Ze QSMI$. The Third, $R\varrho y$, as the Solid $RHOVWIST$. And the Fourth, Rrv, as the Solid $ZabDWXIK$. Fifthly, $\varrho\Upsilon y$, as the Solid $GQRSIMNO$. Sixthly, $r\Upsilon v$, as $IKLMGYZA$. Seventhly, Ryv, as the Solid $IKPOBXVW$. And Lastly, $AIKLMNOR$ will be as the Product of the 3 Numbers of Persons dead, or Υyv. I shall not apply this in all the Cases thereof for brevity-sake; only to shew in one how all the rest may be performed, let it be demanded what is the Value of the Reversion of the younger Life after the two elder proposed. The Proportion is as the whole Number of Chances, or Nnv to the Product Ryv; so is the certain present Value of the Sum payable after any Term proposed, to the Value due to such Chances as the younger Person has to bury both the elder, by the Term proposed; which therefore he is to pay for. Here it is to be noted, that the first Term of all these Proportions is the same throughout, *viz.* Nnv. The second changing yearly according to the Decrease of R, r, ϱ, and Increase of Υ, y, v. And the third are successively the present Values of Money payable after one, two, three, &c. years, according to the Rate of Interest agreed on. These Numbers, which are in all Cases of Annuities of necessary Use, I have put into

Digitized by Google

the following Table, they being the Decimal Values of one Pound payable after the Number of Years in the Margent, at the Rate of *6 per Cent.*

Years.	Pres. Value of 1 *l.*	Years.	Pres. Value of 1 *l.*	Years.	Pres. Value of 1 *l.*
1	0,9434	19	0,3305	37	0,1158
2	0,8900	20	0,3118	38	0,1092
3	0,8396	21	0,2941	39	0,1031
4	0,7921	22	0,2775	40	0,0972
5	0,7473	23	0,2618	45	0,0726
6	0,7050	24	0,2470	50	0,0543
7	0,6650	25	0,2330	55	0,0406
8	0,6274	26	0,2198	60	0,0303
9	0,5919	27	0,2074	65	0,0227
10	0,5584	28	0,1956	70	0,0169
11	0,5268	29	0,1845	75	0,0126
12	0,4970	30	0,1741	80	0,0094
13	0,4688	31	0,1643	85	0,0071
14	0,4423	32	0,1550	90	0,0053
15	0,4173	33	0,1462	95	0,0039
16	0,3936	34	0,1379	100	0,0029
17	0,3714	35	0,1301		
18	0,3503	36	0,1227		

It were needless to advertise, that the great trouble of working so many Proportions will be very much alleviated by using Logarithms; and that instead of using $Nn - ry$ for the second Term of the Proportion in finding the Value of Three Lives, it may suffice to use only ry, and then deducting the fourth Term so found out of the third, the Remainder

Digitized by Google

der ſhall be the preſent Value ſought; or all theſe fourth Terms being added together, and deducted out of the Value of the certain Annuity for ſo many Years, will leave the Value of the contingent Annuity upon the Chance of Mortality of all thoſe Three Lives. For Example; Let there be Three Lives of 10, 30, and 40 Years of Age propoſed, and the Proportions will be thus;

As 661 in 531 in 445 or 156190995, or *Nn*, to 8 in 8 in 9, or 576, or *Y y v* for the firſt Year, ſo 0,9434. to 0,00000348.

To 15 in 16 in 18, or 4320, for the ſecond Year, ſo 0,8900. to 0,00002462.

To 21 in 24 in 28, or 14112 for the third Year, ſo 0,8396. to 0,00008128.

To 27 in 32 in 38, for the fourth Year, ſo 0,7921. to 0,00016650.

To 33 in 41 in 48, for the fifth Year, ſo 0,7473. to 0,00031071.

To 39 in 50 in 58, for the ſixth Year, ſo 0,7050. to 0,00051051.

And ſo forth to the 60th Year, when we ſuppoſe the elder Life of Forty certainly to be expired; from whence 'till Seventy, we muſt compute for the Firſt and Second only, and from thence to Ninety for the ſingle youngeſt Life. Then the Sum Total of all theſe Fourth Proportionals being taken out of the Value of a certain Annuity for 90 Years, being 16, 58 Years Purchaſe, ſhall leave the juſt Value to be paid for an Annuity during the whole Term of the Lives of Three Perſons of the Ages propoſed. And note, that it will

Digitized by Google

will not be necessary to compute for every Year singly; but that in most Cases every 4th or 5th Year may suffice, interpoling for the intermediate Years *secundum artem.*

It may be objected, that the different *Salubrity* of Places does hinder this Proposal from being *universal*; nor can it be denied. But by the Number that die, being 1174. *per Annum* in 34000, it does appear that about a 30th part die yearly, as Sir *William Petty* has computed for *London*; and the Number that die in Infancy, is a good Argument that the Air is but indifferently salubrious. So that by what I can learn, there cannot perhaps be one better Place proposed for a Standard. At least 'tis desired, that in imitation hereof the Curious in other Cities would attempt something of the same Nature, than which nothing perhaps can be more useful.

Were this *Calculus* founded on the Experience of a very great number of Years, it would be very well worth the while to think of Methods for facilitating the Computation of the Value of two, three, or more Lives; which, as proposed in my former, seems (as I am inform'd) a Work of too much Difficulty for the ordinary Arithmetician to undertake.

I have sought, if it were possible, to find a Theorem that might be more concise than the Rules there laid down, but in vain; for all that can be done to expedite it, is, by Tables of Logarithms ready computed, to exhibit the *Rationes* of N to Y in each single Life, for every third, fourth, or fifth Year of Age, as occasion shall require; and these Logarithms being added to the Logarithms of the present

Digitized by Google

present Value of Money payable after so many Years, will give a Series of Numbers, the Sum of which will shew the Value of the Annuity sought. However for each Number of this Series, two Logarithms for a single Life, three for two Lives, and four for three Lives, must necessarily be added together. If you think the Matter, under the Uncertainties I have mentioned, to deserve it, I shall shortly give you such a Table of Logarithms, as I speak of, and an Example or two of the use thereof: But by Vulgar Arithmetick, the Labour of these Numbers were immense; and nothing will more recommend the useful Invention of Logarithms to all Lovers of Numbers, than the advantage of Dispatch in this and such like Computations.

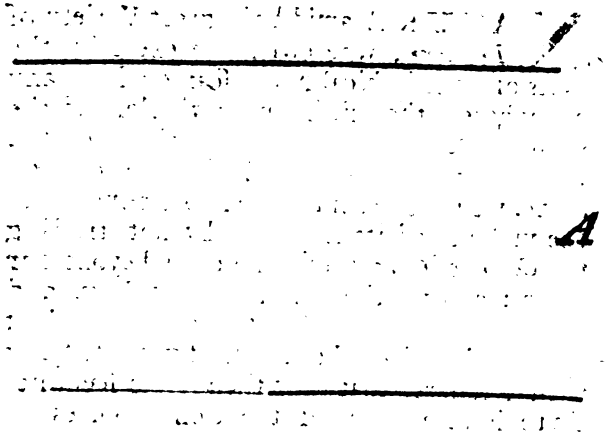
Besides the Uses mentioned, it may perhaps not be an unacceptable thing to infer from the same Tables, how unjustly we repine at the shortness of our Lives, and think our selves wronged if we attain not old Age; whereas it appears hereby, that the one half of those that are born are dead in Seventeen Years time, 1238 being in that time reduced to 616. So that instead of murmuring at what we call an untimely Death, we ought with Patience and Unconcern to submit to that Dissolution which is the necessary Condition of our perishable Materials, and of our nice and frail Structure and Composition: And to account it as a Blessing that we have survived, perhaps by many Years, that Period of Life, whereat the one half of the whole Race of Mankind does not arrive.

Digitized by Google

A second Observation I make upon the said Table, is that the Growth and Increase of Mankind is not so much stinted by any thing in the Nature of the *Species*, as it is from the cautious difficulty most People make to adventure on the State of *Marriage*, from the Prospect of the Trouble and Charge of providing for a Family. Nor are the poorer sort of People herein to be blamed, since their difficulty of subsisting is occasion'd by the unequal Distribution of Possessions, all being necessarily fed from the Earth, of which yet so few are Masters. So that besides themselves and Families, they are yet to work for those who own the Ground that feeds them: And of such does by very much the greater part of Mankind consist; otherwise it is plain, that there might well be four times as many Births as we now find. For by Computation from the Table, I find that there are nearly 15000 Persons above 16 and under 45, of which at least 7000 are Women capable to bear Children. Of these notwithstanding there are but 1238 born yearly, which is but little more than a sixth part: So that about one in six of these Women do breed yearly; whereas were they all married, it would not appear strange or unlikely, that four of six should bring a Child every Year. The Political Consequences hereof I shall not insist on; only the Strength and Glory of a King being in the multitude of his Subjects, I shall only hint, that above all things, Celibacy ought to be discouraged, as, by extraordinary Taxing and Military Service: And those who have numerous Families of Children to be countenanced

Digitized by Google

nanced and encouraged by such Laws as the *Jus trium Liberorum* among the *Romans*. But especially, by an effectual Care to provide for the Subsistence of the Poor, by finding them Employments, whereby they may earn their Bread, without being chargeable to the Publick.



Digitized by Google

A Discourse concerning Gravity, *and its Properties, wherein the Descent of* Heavy *Bodies, and the Motion of* Projects *is briefly, but fully handled: Together with the* Solution *of a* Problem *of great Use in* Gunnery. *By* E. Halley.

NATURE amidst the great Variety of *Problems*, wherewith She exercises the Wits of Philosophical Men, scarce affords any one wherein the Effect is more visible, and the Cause more concealed, than in those of the *Phænomena* of *Gravity*. Before we can go alone, we must learn to defend our selves from the violence of its Impulse, by not trusting the *Center* of *Gravity* of our Bodies beyond our reach; and yet the acutest Philosophers, and the subtilest Enquirers into the Original of this Motion, have been so far from satisfying their Readers, that they themselves seem little to have understood the Consequences of their own *Hypotheses*.

Des Cartes his Notion, I must needs confess to be to me incomprehensible, while he will have the Particles of his *Celestial Matter*, by being reflected on the Surface of the *Earth*, and so ascending therefrom, to drive down into their Places those *Terrestrial Bodies* they find

Digitized by Google

find above them: This is as near as I can gather, the Scope of the 20, 21, 22, and 23 *Sections* of the laſt Book of his *Principia Philoſophiæ*; yet neither he, nor any of his Followers, can ſhew how a Body ſuſpended in *Libero Æthere*, ſhall be carried downwards by a continual Impulſe tending upwards, and acting upon all its Parts equally: And beſides the Obſcurity wherewith he expreſſes himſelf particularly, *Sect.* 23. does ſufficiently argue according to his own Rules, the confuſed *Idea* he had of the thing he wrote.

Others, and among them Dr. *Voſſius*, aſſert the Cauſe of the *Deſcent* of *heavy Bodies*, to be the *Diurnal Rotation* of the *Earth* upon its *Axis*, without conſidering, that according to the Doctrine of Motion fortified with Demonſtration, all Bodies moved *in Circulo*, would recede from the Center of their Motion; whereby the contrary to *Gravity* would follow, and all looſe Bodies would be caſt into the Air in a *Tangent* to the *Parallel* of *Latitude*, without the intervention of ſome other Principle to keep them faſt, ſuch as is that of *Gravity*. Beſides, the Effect of this Principle is throughout the whole Surface of the Globe found nearly equal; and certain Experiments have proved it rather leſs near the *Æquinoctial*, than towards the *Poles*; which could not be by any means, if the *Diurnal Rotation* of the *Earth* upon its *Axis* were the Cauſe of *Gravity*; for where the Motion was ſwifteſt, the Effect would be moſt conſiderable.

Others aſſign the Preſſure of the *Atmoſphere*, to be the Cauſe of this Tendency towards the Center of the Earth; but unhappily they have miſtaken

mistaken the Cause for the Effect; it being from undoubted Principles plain, that the *Atmosphere* has no other Pressure but what it derives from its *Gravity*; and that the Weight of the upper Parts of the *Air*, pressing on the lower Parts thereof, do so far bend the Springs of that *Elastick* Body, as to give it a Force equal to the Weight that compres'd it, having of it self no force at all: And supposing it had, it will be very hard to explain the *Modus*, how that Pressure should occasion the Descent of a Body circumscribed by it, and pressed equally above and below, without some other Force to draw, or thrust it downwards. But to demonstrate the contrary of this Opinion, an *Experiment* was long since shewn before the *Royal Society*, whereby it appeared, that the *Atmosphere* was so far from being the Cause of *Gravity*, that the Effects thereof were much more vigorous, where the Pressure of the *Atmosphere* was taken off; for a long *Glass-Receiver* having a light Down-feather included, being evacuated of Air, the Feather, which in the Air would hardly sink, did *in vacuo* descend with nearly the same *Velocity*, as if it had been a Stone.

Some think to illustrate this Descent of Heavy Bodies, by comparing it with the Vertue of the *Loadstone*; but letting aside the difference there is in the manner of their Attractions, the *Loadstone* drawing only in and about its Poles, and the Earth near equally in all Parts of its Surface, this Comparison avails no more than to explain *ignotum per æque ignotum*.

Others

Digitized by Google

Others assign a certain *Sympathetical Attraction* between the Earth and its Parts, whereby they have, as it were, a desire to be united, to be the Cause we enquire after: But this is so far from explaining the *Modus*, that it is little more, than to tell us in other Terms, that Heavy Bodies descend, because they descend.

This, I say, not that I can pretend to substitute any Solution of this Important Philosophical Problem, that shall more happily explicate the Appearances of Gravity; only it may be serviceable to those with whom the Credit of great Authors sways much, and who too readily assent *in Verba Magistri*, to let them see that their Books are not always infallible: Besides, the detection of Errors is the first and surest Step towards the discovery of Truth.

Tho' the efficient Cause of *Gravity* be so obscure, yet the final Cause thereof is clear enough; for it is by this single *Principle*, that the *Earth* and all the *Celestial Bodies* are kept from *Dissolution*; the least of their *Particles* not being suffer'd to recede far from their *Surfaces*, without being immediately brought down again by virtue of this *Natural Tendency*; which, for their Preservation, the Infinite Wisdom of their *Creator* has ordained to be towards each of their *Centers*; nor can the *Globes* of the *Sun* and *Planets* otherwise be destroy'd, but by taking from them this Power of keeping their Parts united.

The Affections or Properties of *Gravity*, and its manner of acting upon *Bodies falling*, have been in a great measure discovered, and most

Digitized by Google

of them made out by *Mathematical Demonſtration* in this our *Century*, by the accurate diligence of *Galilæus*, *Torricellius*, *Hugenius*, and others, and now lately by our worthy Countryman, Mr. *Iſaac Newton*, which Properties it may be very material here to enumerate, that they may ſerve for a Foundation to all thoſe that ſhall be willing to ſpend their Thoughts in ſearch of the true Cauſe of this *Deſcent* of *Bodies*.

The firſt Property is, That by this Principle of *Gravitation*, all Bodies do deſcend towards a Point, which either is, or elſe is very near to the Center of Magnitude of the Earth and Sea, about which the Sea forms it ſelf exactly into a *Spherical Surface*, and the *Prominences* of the Land, conſidering the Bulk of the whole, differ but inſenſibly therefrom.

Secondly, That this Point or Center of *Gravitation*, is fix'd within the *Earth*, or at leaſt has been ſo, ever ſince we have any *Authentick Hiſtory*: For a Conſequence of its Change, tho' never ſo little, would be the over-flowing of the low Lands on that ſide of the *Globe* towards which it approached, and the leaving new Iſlands bare on the oppoſite ſide, from which it receded; but for this Two thouſand Years it appears, that the low Iſlands of the *Mediterranean Sea* (near to which the ancienteſt Writers lived) have continued much at the ſame height above the Water, as they now are found; and no *Inundations* or *Receſſes* of the *Sea* arguing any ſuch Change, are recorded

Digitized by Google

corded in History; excepting the *Universal Deluge*, which can no better way be accounted for, than by supposing this Center of *Gravitation* removed for a time, towards the middle of the then inhabited Parts of the World; and a change of its Place, but the two thousandth Part of the *Radius* of this *Globe*, were sufficient to bury the Tops of the highest Hills under Water.

Thirdly, That in all Parts of the *Surface* of the *Earth*, or rather in all Points equidistant from its *Center*, the Force of *Gravity* is nearly equal; so that the length of the *Pendulum* vibrating *Seconds of Time*, is found in all Parts of the World to be very near the same. 'Tis true at S. *Helena*, in the *Latitude* of 16 Degrees *South*, I found that the *Pendulum* of my Clock, which vibrated *Seconds*, needed to be made shorter than it had been in *England*, by a very sensible Space (but which at that time I neglected to observe accurately) before it would keep time; and since the like Observations have been made by the *French Observers* near the *Æquinoctial*: Yet I dare not affirm, that in mine it proceeded from any other Cause, than the great Heighth of my Place of Observation above the *Surface* of the *Sea*, whereby the *Gravity* being diminished, the length of the *Pendulum* vibrating *Seconds*, is proportionably shortned.

Fourthly, That *Gravity* does equally affect all *Bodies*, without regard either to their *Matter*, *Bulk*, or *Figure*; so that the Impediment of the *Medium* being removed, the most compact and most loose, the greatest and smallest *Bodies* would descend the same *Spaces* in equal

Digitized by Google

Times; the Truth thereof will appear from the Experiment I before cited. In these two last Particulars, is shewn the great difference between *Gravity* and *Magnetism*, the one affecting only *Iron*, and that towards its *Poles*, the other all *Bodies* alike in every part. As a *Corollary*, from hence it will follow, that there is no such thing as *positive Levity*, those things that appear light, being only comparatively so; and whereas several things rise and swim in *Fluids*, 'tis because, Bulk for Bulk, they are not so heavy as those *Fluids*; nor is there any Reason why *Cork*, for Instance, should be said to be light, because it swims on Water, any more than *Iron*, because it swims on *Mercury*.

5*ly*, That this Power increases as you descend, and decreases as you ascend from the Center, and that in the Proportion of the Squares of the *Distances* therefrom *reciprocally*, so as at a double Distance to have but a quarter of the Force; this Property is the Principle on which Mr. *Newton* has made out all the *Phænomena* of the *Celestial Motions*, so easily and naturally, that its Truth is past Dispute. Besides that, it is higly rational, that the *attractive* or *gravitating* Power should exert it self more vigorously in a small Sphere, and weaker in a greater, in proportion as it is contracted or expanded; and if so, seeing that the *Surfaces* of *Spheres* are as the *Squares* of their *Radii*, this Power, at several Distances, will be as the *Squares* of those *Distances reciprocally*; and then its whole Action upon each *Spherical Surface*, be it great or small, will be always equal. And this is evidently the Rule of *Gravitation*

Digitized by Google

Digitized by Google

Digitized by Google

towards the *Centers* of the *Sun*, *Jupiter*, *Saturn* and the *Earth*, and thence is reaſonably inferred, to be the general Principle obſerved by *Nature*, in all the reſt of the *Celeſtial Bodies*.

Theſe are the principal Affections of *Gravity*, from which the Rules of the *Fall* of *Bodies*, and the *Motion* of *Projects* are *Mathematically* deducible. Mr. *Iſaac Newton* has ſhew'd how to define the Spaces of the *Deſcent* of a *Body*, let fall from any given heighth, down to the *Center*, ſuppoſing the *Gravitation* to increaſe, as in the fifth Property; but conſidering the ſmallneſs of heighth, to which any *Project* can be made aſcend, and over how little an *Arch* of the *Globe* it can be caſt by any of our *Engines*, we may well enough ſuppoſe the *Gravity* equal throughout, and the Deſcents of *Projects* in parallel Lines, which in Truth are towards the *Center*, the difference being ſo ſmall as by no means to be diſcovered in *Practice*. The *Oppoſition* of the *Air*, 'tis true, is conſiderable againſt all light Bodies moving through it, as likewiſe againſt ſmall ones (of which more hereafter) but in great and ponderous Shot, this Impediment is found by *Experience* but very ſmall, and may ſafely be neglected.

Propoſitions concerning the Deſcent of Heavy Bodies, and the Motion of Projects.

Prop. I. The *Velocities* of *falling Bodies*, are proportionate to the Times from the beginning of their *Falls*.

Digitized by Google

This follows, for that the Action of *Gravity* being *continual*, in every Space of Time, the falling Body receives a new Impulse, equal to what it had before, in the same Space of Time, received from the same Power: For Instance, in the first Second of Time, the falling Body has acquired a *Velocity*, which in that time would carry it to a certain Distance, suppose 32 Foot, and were there no new Force, would descend at that rate with an *equable Motion*: But in the next Second of Time, the same Power of *Gravity* continually acting thereon, superadds a new *Velocity* equal to the former; so that at the end of two Seconds, the *Velocity* is double to what it was at the end of the first, and after the same manner may it be proved to be triple, at the end of the third Second, and so on. Wherefore the *Velocities* of *falling Bodies*, are proportionate to the Times of their *Falls*, *Q. E. D.*

Prop. II. The *Spaces* described by the Fall of a Body, are as the *Squares* of the Times, from the beginning of the *Fall*.

Demonstration. Let A B (*Fig.* 9. *Tab.* 4.) represent the *Time* of the *Fall* of a *Body*, B C perpendicular to A B, the *Velocity* acquired at the end of the *Fall*, and draw the Line A C; then divide the Line A B representing the Time, into as many equal Parts as you please, as b, b, b, b, *&c.* and through these Points draw the Lines bc, bc, bc, bc, *&c.* parallel to B C, 'tis manifest that the several Lines, bc, represent the several *Velocities* of the falling Body, in such Parts of the *Time* as A b is of A B, by the former Proposition. It is evident likewise, that the *Area* A B C is the Sum of all

Digitized by Google

all the Lines bc being taken, according to the Method of *Indivisibles*, infinitely many; so that the *Area* ABC represents the Sum of all the *Velocities*, between none and BC supposed infinitely many; which Sum is as the Space descended in the Time represented by AB. And by the same Reason the *Areas* A b c, will represent the Spaces descended in the Times A b; so then the Spaces descended in the Times AB, Ab, are as the *Areas* of the *Triangles* ABC, Abc, which by the 20th of the 6 of *Euclid*, are as the *Squares* of their *Homologous Sides* AB, Ab, that is to say, of the *Times*: Wherefore the Descents of *falling Bodies*, are as the *Squares* of the Times of their *Fall*, *Q. E. D.*

Prop. III. The *Velocity* which a *falling Body* acquires in any Space of time, is double to that, wherewith it would have moved the Space, descended by an equable Motion, in the same *time*.

Demonstration. Draw the Line EC parallel to AB and AE parallel to BC in the same *Fig.* 9. and compleat the *Parallelogram* ABCE, it is evident that the *Area* thereof may represent the Space, a *Body* moved equably with the *Velocity* BC would describe in the Time AB, and the *Triangle* ABC represents the *Space* described by the *Fall* of a *Body*, in the same Time AB, by the second Proposition. Now the *Triangle* ABC is half of the *Parallelogram* ABCE; and consequently the Space described by the *Fall*, is half what would have been described by an *equable Motion* with the *Velocity* BC, in the same Time; wherefore the *Velocity* BC at the

Digitized by Google

end of the *Fall*, is double to that *Velocity*, which in the Time AB, would have described the *Space fallen*, represented by the *Triangle* ABC, with an *equable Motion*, *Q. E. D.*

Prop. IV. All *Bodies* on or near the Surface of the *Earth*, in their *Fall*, descend so, as at the end of the first Second of Time, they have described 16 Feet, 1 Inch, *London Measure*, and acquired the *Velocity* of 32 Feet, 2 Inches, in a Second.

This is made out from the 25th Proposition of the second Part of that excellent Treatise of Mr. *Hugenius de Horologio Oscillatorio*; wherein he demonstrates the time of the least *Vibrations* of a *Pendulum*, to be to the Time of the *Fall* of a *Body*, from the heighth of half the length of the *Pendulum*, as the *Circumference* of a *Circle* to its *Diameter*; whence, as a *Corollary*, it follows, that as the *Square* of the *Diameter* to the *Square* of the *Circumference*, so half the length of the *Pendulum* vibrating *Seconds*, to the *Space* described by the *Fall* of a *Body* in a *Second* of *Time*: And the Length of the *Pendulum* vibrating *Seconds*, being found 39, 125, or $\frac{1}{8}$ Inches, the *Descent* in a *Second* will be found by the aforesaid *Analogy* 16 Foot and 1 Inch; and, by the third Proposition, the *Velocity* will be double thereto; and near to this it hath been found by several Experiments, which by reason of the *swiftness* of the *Fall*, cannot so exactly determine its *Quantity*. The Demonstration of *Hugenius* being the Conclusion of a long Train of *Consequences*, I shall for brevity sake omit; and refer you to his Book, where these things are more amply treated of.

From

Digitized by Google

From these Four *Propositions*, all *Questions* concerning the *Perpendicular Fall of Bodies*, are easily *solved*, and either *Time*, *Height*, or *Velocity* being assigned, one may readily find the other two. From them likewise is the Doctrine of *Projects* deducible, assuming the two following *Axioms*; *viz.* That a *Body* set a moving, will move on continually in a right *Line* with an *equable Motion*, unless some other Force or Impediment intervene, whereby it is accelerated, or retarded, or deflected.

Secondly, That a *Body* being agitated by two *Motions* at a time, does by their *compounded Forces* pass through the same *Points*, as it would do, were the two *Motions divided* and acted *successively*. As for Instance, Suppose a *Body* moved in the Line GF, (*Fig.* 1. *Tab.* 5.) from G to R, and there stopping, by another *Impulse*, suppose it moved in a *Space* of *Time* equal to the former, from R towards K, to V. I say, the *Body* shall pass through the Point V, tho' these two *several Forces* acted both in the *same time*.

Prop. V. The *Motion* of all *Projects* is in the *Curve* of a *Parabola*: Let the *Line* GRF (in *Fig.* 1.) be the *Line* in which the *Project* is directed, and in which by the first *Axiom* it would move equal *Spaces* in equal *Times*, were it not deflected downwards by the Force of *Gravity*. Let GB be the *Horizontal Line*, and GC a *Perpendicular* thereto. Then the *Line* GRF being divided into equal Parts, answering to equal *Spaces* of *Time*, let the *Descents* of the *Project* be laid down in *Lines parallel* to GC, proportioned as the *Squares* of the *Lines* GS, GR, GL, GF, or as the *Squares* of

of the *Times*, from S to T, from R to V, from L to X, and from F to B, and draw the *Lines* TH, VD, XY, BC parallel to GF; I say the Points T, V, X, B, are Points in the *Curve* described by the *Project*, and that that *Curve* is a *Parabola*. By the second *Axiom*, they are Points in the *Curve*; and the Parts of the *Descent* GH, GD, GY, GC, = to ST, RV, LX, FB, being as the *Squares* of the *Times* (by the *second Prop.*) that is, as the *Squares* of the *Ordinates*, HT, DU, YX, BC, equal to GS, GR, GL, GF, the *Spaces* measured in those Times; and there being no other *Curve* but the *Parobola*, whose Parts of the *Diameter* are as the *Squares* of the *Ordinates*, it follows that the *Curve* described by a *Project*, can be no other than a *Parabola*: And saying, as RU the *Descent* in any *time*, to GR or UD the *direct Motion* in the same *time*, so is UD to a *third* proportional; that *third* will be the *Line* called by all Writers of *Conicks*, the *Parameter* of the *Parabola* to the *Diameter* GC, which is always the same in *Projects* cast with the same *Velocity*: And the *Velocity* being defined by the Number of *Feet* moved in a *Second* of Time, the *Parameter* will be found by dividing the *Square* of the *Velocity*, by 16 *Feet*, 1 *Inch*, the *Fall* of a *Body* in the same *Time*.

Lemma.

The *Sine* of the double of any *Arch*, is equal to twice the *Sine* of that *Arch* into its *Co-sine*, divided by *Radius*; and the *versed Sine* of the *double* of any *Arch* is equal to twice the *Square* of the *Sine* thereof divided by *Radius*.

Let

Digitized by Google

Let the *Arch* BC (in *Fig.* 2. *Tab.* 5.) be double the *Arch* BF, and A the *Center*; draw the *Radii* AB, AF, AC, and the *Chord* BDC, and let fall BE perpendicular to AC, and the *Angle* EBC, will be equal to the *Angle* ABD, and the *Triangle* BCE, will be like to the *Triangle* BDA; wherefore it will be as AB to AD, ſo BC or twice BD, to BE; that is, as *Radius* to *Co-ſine*, ſo twice *Sine*, to *Sine* of the double *Arch*. And as AB to BD, ſo twice BD or BC to EC, that is, as *Radius* to *Sine*, ſo twice that *Sine*, to the *Verſed Sine* of the double *Arch*; which two *Analogies* reſolved into *Equations*, are the *Propoſitions* contained in the *Lemma* to be proved.

Prop. VI. The *Horizontal* Diſtances of *Projections* made with the ſame *Velocity*, at ſeveral *Elevations* of the *Line* of Direction, are as the *Sines* of the doubled *Angles* of *Elevation*.

Let GB (*Fig.* 1.) the *Horizontal* Diſtance be $= z$, the *Sine* of the *Angle* of *Elevation*, FGB, be $= s$, its *Co-ſine* $= c$, *Radius* $= r$, and the *Parameter* $= p$. It will be as c to s; ſo z to $\frac{sz}{c} = FB = GC$, and by reaſon of the *Parabola* $\frac{psz}{c}$ $=$ to the *Square* of CB, or GF. Now as c to r, ſo is z to $\frac{zr}{c} = GF$, and its *Square* $\frac{zzrr}{cc}$ will be therefore $= to \frac{psz}{c}$: which *Equation* reduced will be $\frac{psc}{rr} = z$. But by the former *Lemma* $\frac{2sc}{r}$ is equal to the *Sine* of the double

ble *Angle*, whereof *s* is the *Sine*: Wherefore 'twill be as *Radius* to *Sine* of double the *Angle* FGB, so is half the *Parameter*, to the *Horizontal Range* or *Distance* sought; and at the several *Elevations*, the *Ranges* are as the *Sines* of the double *Angles* of *Elevation* *Q. E. D.*

Corollary.

Hence it follows, that half the *Parameter* is the greatest *Random*, and that that happens at the *Elevation* of 45 Degrees, the *Sine* of whose double is *Radius*. Likewise that the *Ranges* equally distant above and below 45 are equal, as are the *Sines* of all doubled *Arches*, to the *Sines* of their doubled *Complements*.

Prop. VII. The *Altitudes* of *Projections* made with the same *Velocity*, at several *Elevations*, are as the *versed Sines* of the doubled *Angles* of *Elevation*: As *c* is to *s* :: so is $\frac{p\,s\,c}{r\,r} = GB$ to $\frac{p\,s\,s}{r\,r} = BF$: and $UK = RU = \frac{BF}{4}$, the *Altitude* of the *Projection* $= \frac{p\,s\,c\,s}{4\,r\,r}$. Now by the foregoing *Lemma* $\frac{2\,s\,s}{r} =$ to the *versed Sine* of the double *Angle*, and therefore it will be as *Radius*, to *versed Sine* of double the *Angle* FGB, so an 8th of the *Parameter* to the height of the *Projection* VK; and so these heights at several *Elevations*, are as the said *versed Sines*, *Q. E. D.*

Corollary.

Digitized by Google

Corollary.

From hence it is plain, that the greatest *Altitude* of the perpendicular *Projection* is a 4th of *Parameter*, or half the greatest *Horizontal Range*; the *versed Sine* of 180 Degrees being $= 2r$.

Prop. VIII. The *Lines* G F, or Times of the Flight of a *Project* cast with the same Degree of *Velocity* at different *Elevations*, are as the *Sines* of the *Elevations*.

As c is to r :: so is $\frac{p \cdot s \cdot c}{rr} =$ GB by the 6 Prop. to $\frac{p\,s}{r} =$ GF, that is, as *Radius* to *Sine* of *Elevation*, so the *Parameter* to the *Line* GF; so the *Lines* GF are as the *Sines* of *Elevation*, and the *Times* are proportional to those *Lines*; wherefore the *Times* are as the *Sines* of *Elevation*: *Ergo constat propositio.*

Prop. IX. Problem. A *Projection* being made as you please, having the Distance and Altitude, or Descent, of an Object, through which the Project passes, together with the *Angle* of *Elevation* of the *Line* of *Direction*; to find the *Parameter* and *Velocity*, that is (in *Fig.* 1.) having the *Angle* FGB, GM, and MX.

Solution. As *Radius* to *Secant* of FGB, so GM the *Distance* given to GL; and as *Radius* to *Tangent* of FGB, so GM to LM. Then LM — MX in *Heights*, or + MX in *Descents*; or else MX — ML, if the *Direction* be below the *Horizontal Line*, is the *Fall* in the *Time* that the direct *Impulse* given in G would have carried the Project from G to L = LX = GY; then by Reason

Reason of the *Parabola*, as LX or GY, is to GL or YX, :: so is GL to the *Parameter* sought. To find the *Velocity* of the *Impulse*: by Prop. 2, and 4, find the Time in Seconds that a Body would fall the Space LX; and by that dividing the Line GL, the *Quote* will be the *Velocity*, or Space moved in a Second sought, which is always a mean Proportional between the *Parameter*, and 16 Feet, 1 Inch.

Prop. X. Problem 2. Having the *Parameter*, Horizontal Distance, and Height or Descent of an *Object*, to find the Elevations of the Line of Direction necessary to hit the given *Object*; that is, having GM, MX, and the greatest *Random* equal to half the *Parameter*; to find the *Angles* FGB.

Let the *Tangent* of the *Angle* sought be $=t$, the *Horizontal Distance* GM $=b$, the Altitude of the *Object* MX $=b$, the *Parameter* $=p$, and *Radius* $=r$, and it will be,

As r to t, so b to $\frac{tb}{r}$ = ML and $\frac{tb}{r} \mp b$ in ascents = LX, and in descents

$\frac{ptb}{r} \mp pb$ = GL *quad.* = XY *quad. ratione Parabolæ*; but

$bb \mp \frac{ttbb}{rr}$ = GL *quad.* 47. 1. *Euclid.* Wherefore

$\frac{ptb}{r} \mp pb = bb \mp \frac{ttbb}{rr}$ which Equation transposed, is

$\frac{ttbb}{rr} = \frac{ptb}{r} \mp pb - bb$, divided by bb is

$\frac{tt}{rr}$

$\frac{tt}{rr} = \frac{pt}{br} \mp \frac{ph}{bb} - 1$. this Equation shews the Question to have 2 Answers, and the Roots thereof are $\frac{t}{r} = \frac{p}{2b} + \sqrt{\frac{pp \mp 4ph}{4bb}} - 1$ from which I derive the following Rule.

Divide half the *Parameter* by the Horizontal distance, and keep the Quote; *viz.* $\frac{p}{2b}$ then say, as *square* of the *distance* given to the half *Parameter*, so half *Parameter* $\mp$ double height descent to the *square* of a *Secant* $= \frac{pp \mp 4ph}{4bb}$. The *Tangent* answering to that *Secant*, will be $\sqrt{\frac{pp \mp 4ph}{4bb}} - 1$ or Square of Radius, so then the sum and difference of the aforefound *Quote*, and this *Tangent* will be the Roots of the *Equation*, and the *Tangents* of the *Elevations* sought.

Note here, that in *Descents*, if the *Tangent* exceed the *Quote*, as it does when ph is more than bb, the *direction* of the lower *Elevation* will be below the *Horizon*, and if $ph = bb$, it must be directed *Horizontal*, and the *Tangent* of the upper *Elevation* will be $\frac{pr}{b}$. Note likewise, that if $4bb + 4ph$ in *ascents*, or $4bb - 4ph$ in *descents*, be equal to pp, there is but one *Elevation* that can hit the *Object*, and its *Tangent* is $\frac{pr}{2b}$. And if $4bb + 4ph$ in *ascents*,

or

Digitized by Google

or $4bb - 4ph$ in *descents*, do exceed pp, the *Object* is without the reach of a *Project* cast with that *Velocity*, and so the thing impossible.

From this *Equation* $4bb + 4ph = pp$ are determined the utmost limits of the reach of any *Project*, and the Figure assigned, wherein are all the *heights* upon each *Horizontal distance* beyond which it cannot pass; for by reduction of that *Equation*, h will be found $= \frac{1}{4}p - \frac{bb}{p}$ in *heights*, and $\frac{bb}{p} - \frac{1}{4}p$ in *descents*; from whence it follows, that all the Points h are in the *Curve* of the *Parabola*, whose *Focus* is the Point from whence the *Project* is cast, and whose *Latus rectum*, or *Parameter ad Axem* is $= p$. Likewise from the same *Equation* may the least *Parameter* or *Velocity* be found capable to reach the *Object* proposed; for $bb = \frac{1}{4}pp + ph$ being reduced $\frac{1}{2}p$ will be $= \sqrt{bb + hh} - h$ in ascents / in descents, which is the *Horizontal Range* at 45 degrees, of a Project cast with the least Velocity that would just reach the *Object*, and the *Elevation* requisite will be easily had; for dividing the so found *Semi-parameter* by the *Horizontal distance* given b, the *Quote* into *Radius* will be the *Tangent* of the *Elevation* sought. This Rule may be of good use to all *Bombardiers* and *Gunners*, not only that they may use no more Pouder than is necessary, to cast their *Bombs* into the place assigned, but that they may shoot with much more certainty, for that a small Error committed in the *Elevation* of the *Piece*, will produce no sensible Difference in the fall of the Shot:

Digitized by Google

Shot: For which Reasons the *French* Engineers in their late Sieges have used Mortar-pieces inclin'd constantly to the *Elevation* of 45, proportioning their Charge of Pouder according to the distance of the *Object* they intend to strike on the *Horizon*.

And this is all that need to be said concerning this *Problem* of shooting upon *Heights* and *Descents*. But if a *Geometrical* Construction thereof be required; I think I have one that is as easy as can be expected, which I deduce from the foregoing *Analytical Solution*, *viz.* $\frac{t}{r} = \frac{p}{2b} \pm \frac{\sqrt{\frac{1}{4}pp \pm ph - bb}}{bb}$, and 'tis this having made the right Angle GDF, (*Tab.* 5. *Fig.* 3.) make DF $= \frac{1}{2}p$, or greatest Range, and GD $= b$ the Horizontal Distance, and DB $= h$ the perpendicular heighth of the Object; to be laid upwards from D, if the Object be above the Horizon, or downwards if below it. Parallel to GD draw FA, and make it equal to GB the Hypothenusal Distance of the Object; and with the Center A and Radius FB $= \frac{1}{2}p \pm h$ sweep an Arch, which shall if the thing be possible, intersect the indeterminate Perpendicular DF in two Points K and L, to which draw the Lines, GL, GK, I say, the Angles DGK, DGL, are the Elevations requisite to strike the Object B.

Demonstration. The Sq. of FK or FL, is equal to FBq − GBq: or $\overline{\frac{1}{2}p \pm h}^2 - bb - hh$ or $\frac{1}{4}pp \pm ph - bb$, and therefore $\sqrt{\frac{1}{4}pp \pm ph - bb}$ is $=$ FK $=$ FL, and by Consequence DK, DL $= \frac{1}{2}p \pm \sqrt{\frac{1}{4}pp \pm ph - bb}$. And as DG: DK and DL:: Radius : Tangents sought,

Digitized by Google

which coincides with our Algebraical Expression thereof.

Prop. XI. To determine the Force or *Velocity* of a *Project*, in every Point of the *Curve* it describes.

To do this we need no other *Præcognita*, but only the third Proposition, *viz.* That the *Velocity* of *falling Bodies*, is double to that which in the same time, would have described the Space *fallen* by an equable Motion: For the *Velocity* of a Project, is compounded of the constant equal *Velocity* of the impressed Motion, and the *Velocity* of the *Fall*, under a given *Angle*, *viz.* the Complement of the *Elevation*: For Instance, in *Fig.* 2. in the time wherein a Project would moue from G to L, it descends from L to X, and by the third *Proposition* has acquired a *Velocity*, which in that time would have carried it by an equable Motion from L to Z, or twice the Descent L X; and drawing the Line G Z, I say, the *Velocity* in the Point X, compounded of the *Velocities* G L and L Z under the Angle G L Z, is to the *Velocity* impress in the Point G, as G Z is to G L; this follows from our second *Axiome*, and by the 20 and 21 *Prop. lib.* 1. *conic. Midorgii*, X O parallel and equal to G Z shall touch the *Parabola* in the Point X. So that the *Velocities* in the several Points, are as the lengths of the *Tangents* to the *Parabola* in those Points, intercepted between any two *Diameters*: And these again are as the *Secants* of the *Angles*, which those *Tangents* continued make with the *Horizontal* Line G B. From what is here laid down, may the comparative Force of a *Shot* in any two Points of the *Curve*, be either *Geometrically* or *Arithmetically* discovered.

Corollary,

Digitized by Google

Corollary.

From hence it follows, that the force of a Shot is always least at U, or the *Vertex* of the *Parabola*, and that at equal distances therefrom, as at T and X, G and B its force is always equal, and that the least force in U is to that in G and B, as *Radius* to the Secant of the *Angle* of *Elevation* F G B.

These *Propositions* considered, there is no question relating to *Projects*, which, by the help of them, may not easily be Solved; and tho' it be true that most of them are to be met withal, in *Galileus Torricellius* and others, who have taken them from those Authors, yet their Books being Forreign, and not easy to come by, and their *Demonstrations* long and difficult, I thought it not amiss to give the whole *Doctrine* here in *English*, with such short *Analytical* Proof of my own, as might be sufficient to evince their Truth.

The Tenth *Proposition* contains a *Problem*, untouch'd by *Torricellius*, which is of the greatest use in *Gunnery*, and for the sake of which this *Discourse* was principally intended: It was first Solved by Mr. *Anderson*, in his Book of the Genuine Use and Effects of the *Gun*, Printed in the Year 1674; but his Solution required so much Calculation, that it put me upon search, whether it might not be done more easily, and thereupon in the Year 1678 I found out the Rule I now Publish, and from it the *Geometrical* Construction: Since which time there has a large *Treatise* of this Subject Intitl'd, *L'art de jetter les Bombes*, been Pub-

Digitized by Google

lish'd by *Monsieur Blondel*, wherein he gives the Solutions of this *Problem* by *Messieurs Buot*, *Romer* and *de la Hire*: But none of them being the same with mine, or, in my Opinion, more easy, and most of them more Operose, and besides mine finding the *Tangent*, which generally determines the *Angle* better than its *Sine*, I thought my self obliged to Print it for the use of all such, as desire to be informed in the *Mathematical* part of the Art of *Gunnery*.

Now these Rules were rigidly true, were it not, as I said before, for the Opposition of the Medium, whereby not only the direct impress-Motion is continually retarded, by likewise the increase of the *Velocity* of the *Fall*, so that the spaces described thereby, are not exactly as the squares of the Times: But what this Opposition of the *Air* is, against several *Velocities*, *Bulks*, and *Weights*, is not so easy to determine. 'Tis certain that the weight of *Air* to that of *Water*, is nearly as 1 to 800, whence the weight thereof, to that of any *Project* is given; 'tis very likely, that to the same *Velocity*, and *Magnitude*, but of different matter, the *Opposition* should be *reciprocally* as the weights of the Shot; as likewise that to Shot of the same *Velocity* and Matter, but of different Sizes, it should be as the *Diameters reciprocally*: Whence generally the *Opposition* to Shot with the same *Velocity*, but of differing *Diameters*, and *Materials*, should be as their *Specifick Gravities* into their *Diameters reciprocally*; but whether the *Opposition*, to differing *Velocities* of the same Shot, be as the *Squares* of those *Velocities*,

ties, or as the *Velocities* themselves, or otherwise, is yet a harder Question. However it be, 'tis certain, that in large Shot of *Mettal*, whose weight many Thousand times surpasses that of the *Air*, and whose force is very great, in proportion to the *Surface* wherewith they press thereon; this *Opposition* is scarce discernable: For by several *Experiments* made with all Care and Circumspection with a *Morterpeice*, Extraordinary well fixt to the Earth on purpose, which carried a solid Brass Shot of four Inches and a half *Diameter*, and of about fourteen Pound Weight, the *Ranges* above and below forty five *Degrees* were found nearly equal; if there were any difference, the under *Ranges* went rather the farthest, but those differences were usually less than the Errours committed in ordinary Practice, by the unequal Goodness and Dryness of the same sort of Pouder, by the Unfittness of the Shot to the Bore, and by the Looseness of the Carriage.

In a smaller Brass-Shot of about an Inch and half Diameter, cast by a Cross-Bow which ranged it, at most about four Hundred Foot, the Force being much more equal than in the Morterpiece, this difference was found more Curiously: and Constantly and most Evidently, the under Ranges out went the upper. From which Trials I conclude, that altho' in small and light Shot, the Opposition of the Air, ought and must be accounted for; yet in Shooting of great and weighty Bombs, there need be very little or no allowance made; and so these Rules may be put in practice to all

Digitized by Google

Intents and Purpoſes, as if this Impediment were abſolutely remov'd.

A Propoſition of general Uſe in the Art of Gunnery, ſhewing the Rule of laying a Mortar to paſs, in order to ſtrike an Object above or below the Horizon.

It was formerly the Opinion of thoſe concerned in Artillery, that there was a certain requiſite of Pouder for each Gun, and that in Mortars, where the diſtance was to be varied, it muſt be done by giving a greater or leſſer Elevation to the Peice. But now our later Experience has taught us that the ſame thing may be more certainly and readily performed by increaſing and diminiſhing the quantity of Pouder, whether regard be had to the Execution to be done, or to the Charge of doing it. For when Bombs are diſcharged with great Elevations of the Mortar, they fall too Perpendicular, and bury themſelves too deep in the Ground, to do all that damage they might, if they came more Oblique, and broke upon or near the Surface of the Earth; which is a thing acknowledged by the Beſieged in all Towns, who unpave their Streets, to let the Bombs bury themſelves, and thereby ſtifle the force of their Splinters. A Second Convenience is, that at the extream Elevation, the Gunner is not obliged to be ſo curious in the direction of his Piece, but it will ſuffice to be within a Degree or two of the Truth; whereas in the other method of Shooting he ought to be very curious. But a Third, and no leſs conſiderable Advantage is, in the ſaving the Prince's

Digitized by Google

Prince's Pouder, which in so great and so numerous Discharges, as we have lately seen, must needs amount to a considerable Value: And for Sea-Mortars, it is scarce practicable otherwise to use them, where the agitation of the Sea continually changes the Direction of the Mortar, and would render the Shot very uncertain, were it not that they are placed about 45 Degrees Elevation, where several Degrees above or under, makes very little difference in the Effect.

In the precedent Discourse, I considered all the Propositions relating to the Motion of Projectiles, and gave a Solution to this Problem; *viz. To hit an Object above or below the Horizontal Line with the greatest Certainty and least Force.* That is, that the Horizontal distance of the Object being put $= b$, and the Perpendicular Heighth $= h$, the Charge requisite to strike the Object with the greatest Advantage, was that which with an Elevation of 45° would cast the Shot on the Horizontal Line, to the distance of $\sqrt{+bb\,bb+b}$ when the Object was above the Horizon; or if it were below it, the Charge must be lesser, so as to reach on the Horizon, at 45° Elevation, no greater a Distance than $\sqrt{bb+bb}-b$; that is, in the one Case, the Sum of the Hypothenusal Distance of the Object from the Gun, and the Perpendicular Heighth thereof above the Gun; and in the other Case, when the Object is below the Horizon, the difference of the same *per* 47. 1 *Eucl.* And I then shew'd how to find the Elevation proper for the Gun so charged, *viz.* As the

Horizontal Distance of the Object, to the Sum or Difference of the Hypothenusal Distance and Perpendicular Height: So Radius to the Tangent of the Elevation sought. But I was not at that time aware that the aforesaid Elevation did constantly bisect the Angle between the Perpendicular and the Object, as is demonstrated from the Difference and Sum of the *Tangent* and *Secant* of any Arch being always equal to the *Tangent* and and *Cotangent* of the half Complement thereof to a Quadrant. Having discovered this, I think nothing can be more compendious, he bids fairer to compleat the Art of Gunnery, it being as easie to shoot with a Mortar at any Object on demand, as if it were on the Level; neither is there need of any Computation, but only simply laying the Gun to pass in the middle Line between the Zenith and the Object, and giving it its due Charge. Nor is there any great need of Instruments for this purpose: For if the Muzzle of the Mortar be turned truly Square to the Bore of the Piece, as it usually is or ought to be, a Piece of Looking-glass Plate applied parallel to the Muzzle, will by its Reflection give the true Position of the Piece, the Bombardeer having no more to do, but to look perpendicularly down on the Looking-glass, along a small Thread with a Plumbet, and to raise or depress the Elevation of the Piece, till the Object appear reflected on the same Point of the *Speculum*, on which the Plumbet falls; for the Angle of Incidence and Reflection being equal, in this Case a Line at Right Angles to the *Speculum*, as is the *Axis* of the Chase of the

Digitized by Google

the Piece, will bisect the Angle between the Perpendicular and the Object, according as our Proposition requires. So that it only remains by good and valid Experiments to be assured of the Force of Gunpouder, how to make and conserve it equal, and to know the Effect thereof in each Piece; that is, how far differing Charges will cast the same Shot out of it; which may most conveniently be engraven on the outside thereof, as a standing Direction to all Gunners, who shall from thence forward have occasion to use that Piece: And were this Matter well ascertained, it might be worth the while to make all Mortars of the like Diameter as near as may be, alike in length of Chase, Weight, Chamber, and all other Circumstances.

This Discovery that the utmost Range on an inclined Plane, is, when the *Axis* of the Piece makes equal Angles with the Perpendicular and the Object, compared with what I have demonstrated of the same Problem in the aforesaid Discourse does lead to and discover two very ready Theorems; the one, to find the greatest Horizontal Range at 45° Elevation, by any Shot made upon any inclined Plane, with any Elevation of the Piece whatsoever: And the other to find the Elevations proper to strike a given Object, with any Force greater than what suffices to reach it with the aforesaid middle Elevation. Both which being performed by one single Proportion, may be very serviceable to such as are concerned in the Practice of Gunnery, but are unwilling to trouble themselves with tedious

Digitized by Google

tedious and difficult Rules. The two Propositions are these.

PROP. I.

A Shot being made on an inclined Plane, having the Horizontal Distance of the Object it strikes, with the Elevation of the Piece, and the Angle at the Gun between the Object and the Perpendicular; to find the greatest Horizontal Range of that Piece, laden with the same Charge; that is, half the *Latus rectum* of all the *Parabole* made with the same *Impetus*.

RULE.

Take half the Distance of the Object from the *Nadir*, and take the Difference of the given Elevation from that half; the Versed Sine of that Difference subtract from the Versed Sine of the Distance of the Object from the *Zenith*: Then shall the Difference of those Versed Sines be to the Sine of the Distance of the Object from the *Zenith*, as the Horizontal Distance of the Object struck, to the greatest Horizontal Range at 45°.

PROP. II.

Having the greatest Horizontal Range of a Gun, the Horizontal Distance and Angle of Inclination of an Object to the Perpendicular, to find the two Elevations necessary to strike that Object.

RULE.

Digitized by Google

RULE.

Halve the Diſtance of the Object from the *Nadir*; this half is always equal to the half Sum of the two Elevations we ſeek. Then ſay, *As the greateſt Horizontal Range is to the Horizontal Diſtance of the Object: So is the Sine of the Angle of Inclination or Diſtance of the Object from the Perpendicular, to a fourth Proportional; which fourth being ſubtracted from the Verſed Sine of the Diſtance of the Object from the* Zenith, *leaves the Verſed Sine of half the Difference of the Elevations ſought; which Elevations are therefore had by adding and ſubtracting that half Difference to and from the aforeſaid half Sum.*

I ſhall not need to ſpeak of the Facility of theſe Solutions, I ſhall only obſerve that they are both General, without Exception or Caution, and derived from the Knowledge that theſe two Elevations are equidiſtant above and below the Line, biſecting the Angle between the Object and the *Zenith*.

Digitized by Google

A Discourse concerning the Measure of the Air's resistance to Bodies moved in it. By the Learned John Wallis, *S. T. D. and R. S. Soc.*

1. THAT the Air (and the like of any other *Medium*) doth considerably give resistance to Bodies moved in it; (and doth thereby abate their Celerity and Force:) is generally admitted. And Experience doth attest it: For otherwise, a Cannot-Bullet projected Horizontally, should (supposing the Celerity and Force undiminished) strike as hard against a perpendicular Wall, erected at a great distance, as near at hand; which we find it doth not.

2. But at what Rate, or in what Proportion, such resistance is; and (consequently, at what Rate the Celerity and Force is continually diminished) seems not to have been so well examined. Whence it is, that the Motion of a Project (secluding this Consideration) is commonly reputed to describe a Parabolick Line; as arising from an uniform or equal Celerity in the Line of Projection, and a Celerity uniformly accelerated in the Line of Descent; which two so compounded, do create a Parabola.

3. In

Digitized by Google

3. In order to the Computation hereof, I first premise this *Lemma*, (as the most rational that doth occur for my first footing,) That (supposing other things equal) the resistance is proportional to the Celerity. For in a double Celerity, there is to be removed (in the same time) twice as much Air, (which is a double Impediment) in a treble, thrice as much; and so in other Proportions.

4. Suppose we then the Force impressed (and consequently the Celerity, if there were no resistance) as 1; the resistance as r. (which must be less than the Force, or else the Force would not prevail over the Impediment, to create a Motion.) And therefore the effective Force at a first Moment, is to be reputed as $1-r$: That is, so much as the Force impressed, is more than the Impediment or Resistance.

5. Be it as $1-r$ to 1; so one to m. (which m is therefore greater than 1,)

6. And therefore the effective Force (and consequently the Celerity) as to a first Moment, is to be $\frac{1}{m}$ of what it would be, had there been no resistance.

7. This $\frac{1}{m}$ is also the remaining Force after such first Moment; and this remaining Force is (for the same Reason) to be proportionally abated as to a second Moment; that is, we are to take $\frac{1}{m}$ thereof, that is $\frac{1}{mm}$ of the impressed Force. And for a third Moment (at equal distance of time) $\frac{1}{mmm}$; for a fourth $\frac{1}{m^4}$; and so onward infinitely.

8. Because

Digitized by Google

8. Because the length dispatched (in equal times) is proportional to the Celerities; the Lines of Motion (answering to those equal Times) are to be as m, $m^{\frac{1}{2}}$, $m^{\frac{1}{3}}$, $m^{\frac{1}{4}}$, *&c.* of what they would have been, in the same Times, had there been no resistance.

9. This therefore is a Geometrical Progression; and (because of m greater than 1) continually decreasing.

10. This decreasing Progression infinitely continued (determining in the same Point of Rest, where the Motion is supposed to expire) is yet of a finite Magnitude; and equal to $m^{\frac{1}{m-1}}$ of what it would have been in so much Time, if there had been no resistance. As is demonstrated in my Algebra, *Chap.* 95. *Prop.* 8. For (as I have elsewhere demonstrated) the Sum or Aggregate of a Geometrical Progression is $\frac{VR-A}{R-1}$ (supposing V the greatest Term, A the least, and R the common Multiplier.) That is $\frac{VR}{R-1} - \frac{A}{R-1}$. Now in the present Case, (supposing the Progression infinitely continued) the least Term A, becomes infinitely small, or $= 0$. And consequently $\frac{A}{R-1}$ doth also vanish, and thereby the Aggregate becomes $= \frac{VR}{R-1}$. That is

at is, ſo con-
Antecedent
or as *m* to
F, *AL*, *AN*,
of continual
re alſo conti-
ſame propor-
e ſuch Propor-
b, *c*, &c. That
=*c*, &c.
&c. are in con-
:: C. D :: &c.
— C. C :: C — D.
:: *d*. D :: &c.
:: B. C. D. &c. ::
portion as A to
the Hyperbolick
are equal. As is
n-Vincent; and as
In, &c. may fitly
n which are dif-
repreſented by *FL*,
e in Number infi-
finite Magnitude)
And conſequently
Motion thence ari-

Digitized by Google

Now because (as is well known) all the inscribed Parellelograms, in the exterior Hyperbola, AS, AH, &c. are equal; and therefore their sides reciprocal: Therefore as $Ad = 1 \div m$ (supposing Bd to be taken, from B toward A,) to $AB = 1$, (or as $m - 1$ to m:) so is $BS = \frac{1}{m} DH$, to dh, which is therefore equal to $\frac{1}{m-1}$ of DH; that is (as will appear by dividing 1 by $m - 1$,) to $\frac{1}{m} + \frac{1}{mm} + \frac{1}{m^3}$ &c. of DH.

$$m-1)\ 1\ \left(\frac{1}{m}+\frac{1}{mm}+\frac{1}{m^3}+\text{&c.}\right.$$
$$\frac{1-\frac{1}{m}}{\frac{1}{m}}$$
$$\frac{\frac{1}{m}-\frac{1}{mm}}{\frac{1}{mm}}$$
$$\frac{\frac{1}{mm}-\frac{1}{m^3}}{\frac{1}{m^3}}$$
$$\text{&c.}$$

Or if Bd be taken beyond B, then as $Ad = 1 + m$, to $AB = 1$, or as $m + 1$ to m, so is $m\ DH$ to dh, which is therefore equal to $m + 1\ DH$; that is (as will appear by like dividing of 1 by $m + 1$,) to $\frac{1}{m} - \frac{1}{mm} + \frac{1}{m^3}$ &c. of DH.

12. Let such ordinate dh, or (equal to it in the Asymptote) AF, be so divided in L, M, N, &c. (by Perpendiculars cutting the Hyperbola in l, m, n, &c.) as that FL, LM, MN

Digitized by Google

MN be as m, $m\,m$, m^3 &c. That is, so continually decreasing, as that each Antecedent be to its Consequent, as 1 to m, or as m to 1. See *Fig.* 5. *Tab.* 5.

13. This is done by taking AF, AL, AN, &c. in such proportion. For, of continual Proportionals, the differences are also continually proportional, and in the same proportion. For let A, B, C, D, &c. be such Proportionals, and their Differences a, b, c, &c. That is $A - B = a$, $B - C = b$, $C - D$, $= c$, &c.

Then, because A, B, C, D, &c. are in continual proport.
That is A. B :: B. C :: C. D :: &c.
And dividing A − B. B :: B − C. C :: C − D. D :: &c.
That is *a*. B :: *b*. C :: *d*. D :: &c.
And alternly *a*. *b*. *c*. &c. :: B. C. D. &c. :: A. B. C. &c.
That is, in continual proportion as A to B, or as m to 1.

14. This being done; the Hyperbolick Spaces Fl, Lm, Mn, &c. are equal. As is demonstrated by *Gregory San-Vincent*; and as such is commonly admitted.

15. So that Fl, Lm, Mn, &c. may fitly represent equal Times, in which are dispatched unequal Lengths, represented by FL, LM, MN, &c.

16. And because they are in Number infinite (though equal to a finite Magnitude) the Duration is infinite: And consequently the impressed Force, and Motion thence arising,

sing, never to be wholly extinguished (without some further Impediment) but perpetually approaching to A, in the Nature of Asymptotes.

17. The Spaces Fl, Fm, Fn, &c. are therefore as Logarithms (in Arithmetical Progression increasing) answering to the Lines AF, AL, AM, &c. or to FL, LM, MN, &c. in Geometrical Progression decreasing.

18. Because FL, LM, MN, &c. are as $\frac{1}{m}$, $\frac{1}{mm}$, $\frac{1}{m^3}$, &c. (infinitely) terminated at A; therefore (by ¶ 10) their Aggregate FA or dh, is to DH, (so much Length as would have been dispatched, in the same time, by such impressed Force undiminished) as 1 to $m - 1 = n$.

19. If therefore we take, as 1 to n, so AF to DH; this will represent the Length to be dispatched, in the same time, by such undiminished Force.

20. And if such DH be supposed to be divided into equal Parts innumerable (and therefore infinitely small;) these answer to those (as many) Parts unequal in FA, or hd.

21. But, what is the Proportion of r to 1, or (which depends on it) of $1 - r$ to 1, or 1 to m; remains to be inquired by Experiment.

22. If the Progression be not infinitely continued; but end (suppose) at N, and its last Term be AN; then, out of $\frac{V}{R-1} = \frac{1}{m} + \frac{1}{mm} + \frac{1}{m^3}$, &c. is to be subducted $\frac{A}{R-1}$ (as at ¶ 10) that is (as by Divi-

sion

ſion will appear) $\frac{A}{R} + \frac{A}{R^2} + \frac{A}{R^3}$ &c. That is (in our preſent Caſe) $\frac{a}{m} + \frac{a}{m^2} + \frac{a}{m^3}$ &c. And ſo the Aggregate will be $\frac{1-a}{m} + \frac{1-a}{m^2} + \frac{1-a}{m^3}$ &c. $= \frac{1-a}{n}$.

And thus as to the Line of Projection, in which (ſecluding the Reſiſtance,) the Motion is reputed uniform, diſpatching equal Lengths in equal Times. Conſider we next the Line of Deſcent.

23. In the Deſcent of Heavy Bodies, it is ſuppoſed that to each Moment of Time, there is ſuperadded a new Impulſe of Gravity to what was before: And each of theſe, ſecluding the Conſideration of the Air's Reſiſtance, to proceed equally (from their ſeveral beginnings) through the ſucceeding Moments. As (in the erect Lines) 1 1 1 1 &c. 1 1 1 &c. 1 1 &c. 1 &c. and ſo continually as in the Line of Projection.

24. Hence ariſeth (in the tranſverſe Lines) for the firſt Moment 1, for the ſecond 1 + 1, for the third 1 + 1 + 1, and ſo forth, in Arithmetical Progreſſion: As are the Ordinates in a Triangle, at equal diſtance.

25. And ſuch are the continual Increments of the Diameter, or of the Ordinates in the exterior Parabola, anſwering to the interior Ordinates, or Segments of the Tangent, equally increaſing; as is known, and commonly admitted.

26. If we take in the Consideration of the Air's Resistence; we are then for each of these equal Progressions, to substitute a decreasing Progression Geometrical; in like manner (and for the same Reasons) as in the Line of Projection.

27. Hence ariseth, for the first Moment $\frac{1}{m}$; for the second $\frac{1}{m} + \frac{1}{m^2}$; for the third $\frac{1}{m} + \frac{1}{m^2} + \frac{1}{m^3}$ &c. And such is therefore the Descent of a heavy Body falling by its own weight. The several Impulses of Gravity being supposed equal.

28. That is (in the Figure of ¶ 12) as FL, FM, FN, &c. in the Line of Descent, answering to FL, LM, MN, &c. in the Line of Projection.

29. But though the Progressions for the Line of Projection, are like to each of those many in the Line of Descent; it is not to be thence inferred, that therefore m in the one, is equal to m in the other: But in the Line of Projection (suppose) $\frac{1}{m}f$ (such a Part of the Force impressed, and a Celerity answerable:) in the Line of Descent, $\frac{1}{m}g$ such a Part of the Impulse of Gravity.

30. Those for the Line of Descent (of the same Body) are all equal, each to other: Because g (the new Impulse of Gravity) in each Moment is supposed to be the same.

31. But

Digitized by Google

31. But what is the Proportion of f to g (that of the Force impressed, to the Impulse of Gravity in each Body) remains to be inquired by Experiment.

32. This Proportion being found as to one known Force; the same is thence known as to any other Force, (who's Proportion to this is given) in the same uniform *Medium*.

33. And this being known as to one *Medium*; the same is thence known as to any other *Medium*, the Proportion of whose Resistance to that of this is known.

34. If a heavy Body be projected downward in a perpendicular Line, it descends therefore at the Rate $\frac{1}{m}$, $\frac{1}{mm}$, $\frac{1}{m^3}$, &c. of f (the impressed Force, increased by $\frac{1}{m}$, $\frac{1}{m}+\frac{1}{m^2}$, $\frac{1}{m}+\frac{1}{m^2}+\frac{1}{m^3}$, &c. of g the Impulse of Gravity, (by ¶ 7. and ¶ 27.) Because both Forces are here united.

35. If in a perpendicular Projection upwards; it ascends in the rate of the former, abated by that of the latter, Because here the Impulse of Gravity is contrary to the Force impressed.

36. When therefore this latter (continually increasing) becomes equal to that former (continually decreasing) it then ceaseth to ascend; and doth thenceforth descend at the rate wherein the latter continually exceeds the former.

37. In an Horizontal, or Oblique Projection: If to a Tangent, whose Increments are as FL, LM, MN, &c. that is as $-\frac{1}{m}f$, &c. be fitted Ordinates (at a given Angle) whose

Digitized by Google

Increments are as FL, FM, FN, &c. that is, as $\frac{I}{m}g$, &c. The Curve answering to the Compound of these Motions, is that wherein the Project is to move.

38. This Curve (being hitherto without a Name) may be called *Linea Projectorum*; the Line of Projects, or things projected; which resembles a Parabola deformed.

39. The Celerity and Tendency, as to each Point of this Line, is determined by a Tangent at that Point.

40. And that against which it makes the greatest Stroke or Percussion, is that which (at that Point) is at right Angles to that Tangent.

41. If the Projection (at ¶ 27.) be not infinitely continued, but terminate (suppose) at N, so that the last Term in the first Column or Series erect be a; and consequently in the second, mn, in the third, mmk, &c. (each Series having one Term fewer than that before it:) then (for the same Reasons as at ¶ 22.) the Aggregates of the several Columns (or erect Series) will be $\frac{I-a}{n}$, $\frac{I-mn}{n}$, $\frac{I-mma}{n}$, and so forth, till (the Multiple of a becoming $=I$) the Progression expire.

42. Now all the Abatements here, k, mk, mmg, &c. are the same with the Terms of the first Column taken backward. For a is the last, mn the next before it; and so of the rest.

43. And

Digitized by Google

43. And the Aggregate of all the Numerators is so many times 1, as is the Number of Terms (suppose t,) wanting the first Column; that is $t - \frac{1-a}{n}$, or $\frac{nt-1+a}{n}$; and this again divided by the common Denominator n, becomes $\frac{nt-1+a}{nn}$. And therefore $\frac{nt-1+a}{nn}g$ is the Line of Descent by its own Gravity.

44. If therefore this be added to a projecting Force downward in a Perpendicular; or subducted from such projecting Force upward; that is, to or from $\frac{1-a}{n}f$: The Descent in the first Case will be $\frac{1-a}{n}f + \frac{nt-1+a}{nn}g$; and the Ascent in the other case $\frac{1-a}{n}f - \frac{nt-1+a}{nn}g$. And in this latter Case, when the ablative Part becomes equal to the positive Part, the Ascent is at the highest; and thenceforth (the ablative Part exceeding the positive) it will descend.

45. In an Horizontal or Oblique Projection, having taken $\frac{1-a}{n}f$ in the Line of Projection, and thence (at the Angle given) $\frac{nt-1+a}{nn}g$ in the Line of Descent; the Point in the Curve answering to these, is the Place of the Project answering to that Moment.

Increments are as *FL*, *FM*, *FN*, &c. that is, as $\frac{t}{m}g$, &c. The Curve answering to the Compound of these Motions, is that wherein the Project is to move.

38. This Curve (being hitherto without a Name) may be called *Linea Projectorum*; the Line of Projects, or things projected; which resembles a Parabola deformed.

39. The Celerity and Tendency, as to each Point of this Line, is determined by a Tangent at that Point.

40. And that against which it makes the greatest Stroke or Percussion, is that which (at that Point) is at right Angles to that Tangent.

41. If the Projection (at ¶ 27.) be not infinitely continued, but terminate (suppose) at *N*; so that the last Term in the first Column or Series erect be a; and consequently in the second, ma, in the third, mma, &c. (each Series having one Term fewer than that before it:) then (for the same Reasons as at ¶ 22.) the Aggregates of the several Columns (or erect Series) will be $\frac{1-a}{n}$, $\frac{1-ma}{n}$, $\frac{1-mma}{n}$, and so forth, till (the Multiple of a becoming $=1$) the Progression expire.

42. Now all the Abatements here, a, ma, mma, &c. are the same with the Terms of the first Column taken backward. For a is the last, ma the next before it; and so of the rest.

43. And

43. And the Aggregate of all the Numerators is so many times 1, as is the Number of Terms (suppose t,) wanting the first Column; that is $t - \frac{1-a}{n}$, or $\frac{nt-1+a}{n}$; and this again divided by the common Denominator n, becomes $\frac{nt-1+a}{nn}$. And therefore $\frac{nt-1+a}{nn}$ g, is the Line of Descent by its own Gravity.

44. If therefore this be added to a projecting Force downward in a Perpendicular; or subducted from such projecting Force upward; that is, to or from $\frac{1-a}{n} f$: The Descent in the first Case will be $\frac{1-a}{n} f + \frac{nt-1+a}{nn} g$; and the Ascent in the other case $\frac{1-a}{n} f - \frac{nt-1+a}{nn} g$. And in this latter Case, when the ablative Part becomes equal to the positive Part, the Ascent is at the highest; and thenceforth (the ablative Part exceeding the positive) it will descend.

45. In an Horizontal or Oblique Projection, having taken $\frac{1-a}{n} f$ in the Line of Projection, and thence (at the Angle given) $\frac{nt-1+a}{nn} g$ in the Line of Descent; the Point in the Curve answering to these, is the Place of the Project answering to that Moment.

46. I am aware of ſome Objections to be made, whether to ſome Points of the Proceſs, or to ſome of the Suppoſitions. But I ſaw not well how to wave it, without making the Computation much more perplex'd. And in a Matter ſo nice, and which muſt depend upon Phyſical Obſervations, 'twill be hard to attain ſuch Accuracy, as not to ſtand in need of ſome Allowances.

47. Somewhat might have been farther added to direct the Experiments ſuggeſted at ¶ 21, and 31. But that may be done at leiſure, after deliberation had, which way to attempt the Experiment.

48. The like is to be ſaid of the different reſiſtance which different Bodies may meet with in the ſame *Medium*, according to their different Gravities (extenſively or intenſively conſidered) and their different Figures and Poſitions in Motion. Whereof we have hitherto taken no account; but ſuppoſed them, as to all theſe, to be alike and equal.

Poſt-ſcript.

49. The Computation in ¶ 41, 42, 43, may (if that be alſo deſired) be thus repreſented by Lines and Spaces. The Ablatives *a*, *m a*, *m m a*, &c. (being the ſame with the firſt Column taken backward) are fitly repreſented by the Segments of *N F* (beginning at *N*) in Figure 5. and 6. and therefore by Parallelograms on theſe Baſes, aſſuming the common height of *P h*, or *N Q*; the Aggregate of which is *N h*, or *P Q*. And, ſo many times 1, by ſo many equal Spaces, on the ſame Baſes,

Digitized by Google

ſes, between the ſame Parallels, terminated at the Hyperbola: The Aggregate of which is *bFNQn*. From whence if we ſubduct the Aggregate of Ablatives *FQ*; the remaining trilinear *bQn*, repreſents the Deſcent.

50. If to this of Gravity, be joined a projecting Force; which is to the Impulſe of Gravity as *bK* to *bF* (be it greater, leſs, or equal) taken in the ſame Line; the ſame Parallels determine proportional Parallelograms, whoſe Aggregate is *KQ*.

51. And therefore if this be a perpendicular Projection downwards; then *bKkn* (the Sum of this with the former) repreſents the Deſcent.

42. If it be a Perpendicular upwards; then the difference of theſe two repreſents the Motion; which ſo long as *KQ* is the greater, is Aſcendent; but Deſcendent, when *bQn* becomes greater; and it is then at the higheſt when they be equal.

53. If the Projection be not in the ſame Perpendicular, (but Horizontal, or Oblique) then *KQ* repreſents the Tangent of the Curve; and *bQn* the Ordinates to that Tangent, at the given Angle.

54. But the Computation before given, I take to be of better uſe than this Repreſentation in Figure. Becauſe in ſuch Mathematical Enquiries, I chuſe to ſeparate (as much as may be) what purely concerns Proportions; and conſider it abſtractly from Lines, or other Matter wherewith it is incumbered.

As

As to the Question proposed; whether the resistance of the *Medium* do not always take off such a proportional part of the Force moving through it, as is the specifick Gravity of the *Medium* to that of the Body moved in it: (for, if so, it will save us the trouble of Observation.)

I think this can by no means be admitted. For there be many other things of Consideration herein, beside the intensive Gravity (or, as some call it, the specifick Gravity) of the *Medium*.

A viscous *Medium* shall more resist, than one more fluid, though of like intensive Gravity.

And a sharp Arrow shall bore his way more easily through the *Medium*, than a blunt-headed Bolt, though of equal Weight, and like intensive Gravity.

And the same Pyramid with the Point, than with the Base forward.

And many other like Varieties, intended in my ¶ 48.

But this I think may be admitted, namely, That different *Mediums*, equally liquid, (and other Circumstances alike,) do in such proportion resist, as is their intensive Gravity. Because there is, in such proportion, a heavier Object to be removed, by the same Force. Which is one of the things to which ¶ 33 refers.

And again: The heavier Project once in Motion, (being equally swift, and all other Circumstances alike) moves through the same *Medium* in such proportion more strongly, as is its intensive Gravity. For now the Force is

is in such proportion greater, for the removal of the same resistance. And this Part of what my ¶ 32 insinuates.

But where there is a Complication of these Considerations one with another, and with many other Circumstances, whereof each is severally to be considered; there must be respect had to all of them.

An Instance of the Excellence of the Modern Algebra, *in the Resolution of the Problem of finding the* Foci *of Optick Glasses universally.* By E. Halley, *S. R. S.*

THE Excellence of the *Modern Geometry* is in nothing more evident, than in those full and adequate Solutions it gives to Problems; representing all the possible Cases at one view, and in one general Theorem, many times comprehending whole Sciences; which deduced at length into Propositions, and demonstrated after the manner of the *Ancients*, might well become the Subjects of large Treatises: For whatsoever Theorem solves the most complicated Problem of the kind, does with a due Reduction reach all the subordinate Cases. Of this I now design to give a notable Instance in the Doctrine of *Dioptricks*.

This Dioptrick Problem is that of finding the *Focus* of any sort of *Lens*, exposed either to converging, diverging, or parallel Rays of Light, proceeding from, or tending to a given Point in the *Axis* of the *Lens*, be the *Ratio* of *Refraction* what it will, according to the Nature of the transparent Material whereof the *Lens* is formed, and also with allowance for the thickness of the *Lens* between the *Vertices*

Digitized by Google

tiees of the two Spherical Segments. This Problem being solved in one Case, *mutatis mutandis*, will exhibit Theorems for all the possible Cases, whether the *Lens* be *Double-Convex* or *Double-Concave*, *Plano-Convex*, or *Plano-Concave*, or *Convexo-Concave*, which sort are usually called *Menisci*. But this is only to be understood of those Beams which are neareſt to the *Axis* of the *Lens*, so as to occasion no sensible difference by their Inclination thereto; and the *Focus* here formed, is by *Dioptrick Writers* commonly called the principal *Focus*, being that of use in *Telescopes* and *Microscopes*.

Let then (in *Fig.* 7. *Tab.* 5.) BEβ be a double Convex *Lens*, C the Center of the Segment EB, and K the Center of the Segment Eβ, Bβ the thickness of the *Lens*, D a Point in the *Axis* of the *Lens*; and it is required to find the Point F, at which the Beams proceeding from the Point D, are collected therein, the *Ratio* of Refraction being as m to n. Let the distance of the Object DB=DA=d (the Point A being supposed the same with B, but taken at a distance therefrom, to prevent the coincidence of so many Lines) the *Radius* of the Segment towards the Object CB or CA=r, and the *Radius* of the Segment from the Object Kβ or Kα=ϱ; and let Bβ the thickness of the *Lens* be =t, and then let the Sine of the Angle of Incidence DAG be to the Sine of the refracted Angle HAG or CAφ as m to n: And in very small Angles, the Angles themselves will be in the same proportion; whence it will follow that,

As d to r, so the Angle at C to the Angle at D, and $d-r$ will be as the Angle of Inci-

dence

dence GAD; and again as m to n, so $d+r$ to $\frac{dn+rn}{m}$, which will be as the Angle GAH=CAφ. This being taken from ACD which is as d, will leave $\frac{md-nr}{m}$ analogous to the Angle AφD; and the Sides being in this Case proportional to the Angles they subtend, it will follow, that as the Angle AφD is to the Angle ADφ, so is the Side AD or BD to Aφ or Bφ: That is, Bφ will be $=\frac{mdr}{md-nr}$, which shews in in what Point the Beams proceeding from D, would be collected by means of the first Refraction; but if nr cannot be substracted from md, it follows that the Beams after Refraction do still pass on diverging, and the Point φ is on the same side of the *Lens* beyond D. But if nr be equal to md, then they proceed parallel to the *Axis*, and the Point φ is infinitely distant.

The Point φ being found as before, and Bφ—Bβ being given, which we will call δ, it follows by a Process like the former, that βF, or the focal Distance sought, is equal to $\frac{\delta\varrho n}{m-n\delta+m\varrho}=f$. And in the room of δ substituting Bφ—Bβ $=\frac{mdr}{md-nr}-t$, putting p for $\frac{n}{m-n}$ after due Reduction this following Equation will arise,

$$\frac{npdr\varrho-nd\varrho t+npr\varrho t}{md-nd\varrho-mpr\varrho-mdt+nrt}=f.$$

Which

Which Theorem, however it may seem operose, is not so, considering the great Number of *Data* that enter the Question; and that one half of the Terms arise from our taking in the thickness of the *Lens*, which in most Cases can produce no great Effect; however it was necessary to consider it, to make our Rule perfect. If therefore the *Data* consist of *Glass*, whose Refraction is as 3 to 2 'twill be $\frac{6drq - 2dqt + 4rqt}{3dr + 3dq - 6rq - dt + 2rt} = f$. If of *Water*, whose Refraction is as 4 to 3 the Theorem will stand thus $\frac{12drq - 3dqt + 9rqt}{4dr + 4dq - 12rq - dt + 3rt} = f$. If it could be made of *Diamant*, whose Refraction is as 5 to 2, it would be $\frac{\frac{5}{3}drq - 2dqt + \frac{2}{3}rqt}{5dr + 5dq - \frac{10}{2}rq - 3dt + 2rt} = f$. And this is the universal Rule for the *Foci* of double Convex Glasses exposed to diverging Rays. But if the thickness of the *Lens* be rejected as not sensible, the Rule will be much shorter, *viz.* $\frac{pdrq}{dr + dq - prt} = f$, or in Glass $\frac{2drq}{dr + dq - 2rq} = f$. all the Terms wherein t is found being omitted, as equal to nothing. In this Case, if d be so small, as that $2rq$ exceed $dr + dq$, then will it be $-f$, or the *Focus* will be Negative, which shews that the Beams after both Refractions still proceed diverging.

To bring this to the other Cases, as of converging Beams, or of Concave Glasses, the Rule

Rule is ever composed of the same Terms, only changing the Signs of + and −; for the distance of the Point of Concourse of converging Beams, from the Point B, or the first Surface of the *Lens*, I call a negative distance or $-d$; and the Radius of a Concave *Lens* I call a negative Radius, or $-r$ if it be the first Surface, and $-\varrho$, if it be the second Surface. Let then converging Beams fall on a double Convex of Glass, and the Theorem will stand thus $\frac{-2\,d\,r\,\varrho}{-d\,r+d\,\varrho-2\,r\,\varrho}=+f$, which shews that in this Case the *Focus* is always affirmative.

If the *Lens* were a *Meniscus* of Glass, exposed to diverging Beams, the Rule is $\frac{-2\,d\,r\,\varrho}{-d\,r+d\,\varrho+2\,r\,\varrho}=f$, which is affirmative when $2\,r\,\varrho$ is less than $d\,r-d\,\varrho$, otherwise negative: But in the Case of converging Beams falling on the same *Meniscus*, 'twill be $\frac{+2\,d\,r\,\varrho}{+d\,r-d\,\varrho+2\,r\,\varrho}=f$. and it will be $+f$, whilst $d\,\varrho-d\,r$ is less than $2\,r\,\varrho$; but if it be greater than $2\,r\,\varrho$, it will always be found negative or $-f$. If the *Lens* be double Concave, the *Focus* of converging Beams is negative, where it was affirmative in the Case of diverging Beams on a double Convex; *viz.* $\frac{-2\,d\,r\,\varrho}{+d\,r+d\,\varrho-2\,r\,\varrho}=f$, which is affirmative only when $2\,r\,\varrho$ exceeds $d\,r+d\,\varrho$: But diverging Beams passing a double Concave, have always a negative *Focus*, *viz.* $\frac{-2\,d\,r\,\varrho}{+d\,r+d\,\varrho+2\,r\,\varrho}=-f$.

The

The Theorems for converging Beams, are principally of use to determine the *Focus* resulting from any sort of *Lens* placed in a Telescope, between the *Focus* of the Object-glass and the Glass it self; the distance between the said *Focus* of the Object-glass, and the interposed *Lens* being made $= d$.

I here suppose my Reader acquainted with the Rules of Analytical Multiplication and Division, as that $+$ multiplied by $+$ makes the Product $+$, $+$ by $-$ makes $-$, and $-$ by $-$ makes $+$, so dividing $+$ by $+$ makes the Quote $+$, $+$ by $-$ makes $-$, and $-$ by $-$ makes $+$, which will be necessary to be understood in the preceding Examples.

In case the Beams are parallel, as coming from an infinite distance, (which is supposed in the Case of Telescopes) then will d be supposed Infinite, and in the Theorem $\frac{p\,d\,e\,r}{d\,r + d\,e - p\,r\,e}$ the Term $p\,r\,e$ vanishes, as being finite, which is no part of the other infinite Terms; and dividing the remainder by the infinite Part d, the Theorem will stand thus $\frac{p\,e\,r}{r+e} = f$, or in Glass, $\frac{2\,r\,e}{r+e} = f$.

In case the *Lens* were *Plano-Convex* exposed to diverging Beams, instead of $\frac{p\,d\,e\,r}{d\,r + d\,e - p\,r\,e}$, r being infinite, it will be $\frac{p\,d\,e}{d - p\,e} = f$, or $\frac{2\,d\,e}{d + 2\,e} =$ if the *Lens* be Glass.

If the *Lens* be Double-Convex, and r be equal to e, as being formed of Segments of

Digitized by Google

equal Spheres, then will $\frac{pdqr}{dr+dq-prq}$ be reduced to $\frac{pdr}{2d-pr}f$; and in case d be infinite, then it will yet be farther contracted to $\frac{1}{2}pr$, and p being $=\frac{n}{m-n}$ the focal distance in Glass will be $=r$, in Water $1\frac{1}{2}r$, but in Diamant $\frac{1}{3}r$.

I am sensible that these Examples are too much for the compleat Analyst, though I fear too little for the less Skilful; it being very hard, if possible, in such Matters, so to write as to give satisfaction to both; or to please the one, and instruct the other. But this may suffice to shew the extent of our Theorem, and how easie a Reduction adapts any one case to all the rest.

Nor is this only useful to discover the *Focus* from the other proposed *data*, but from the *Focus* given, we may thereby determine the distance of the Object; or from the *Focus* and Distance given, we may find of what Sphere it is requisite to take another Segment, to make any given Segment of another Sphere cast the Beams from the distance d to the *Focus* f. As likewise from the *Lens*, *Focus*, and Distance given, to find the *Ratio* of Refraction, or of m to n, requisite to answer those *Data*. All which it is obvious, are fully determined from the Equation we have hitherto used, *viz.* $pdqr=drf+dqf-prqf$, for to find d the Theorem is $\frac{prqf}{rf+qf-pqr}=d$, the distance of the Object.

For

For e the Rule is $\frac{drf}{pdr+df+prf} = e$.

But for p will be $\frac{drf+def}{der+fer} = p$, which latter determines the *Ratio* of Refraction, m being to n as $1+p$ to p.

I shall not expatiate on these Particulars, but leave them for the Exercise of those that are desirous to be informed in Optical Matters, which I am bold to say are comprehended in these three Rules, as fully as the most Inquisitive can desire them, and in all possible Cases; regard being had to the Signs $+$ and $-$, as in the former Cases of finding the *Focus*. I shall only shew two considerable Uses of them; the one to find the distance whereat an Object being placed, shall by a given *Lens* be represented in a *Species* as large as the Object it self, which may be of singular Use in drawing Faces, and other things in their true Magnitude, by transmitting the *Species* by a Glass into a dark Room, which will not only give the true Figure and Shades, but even the Colours themselves, almost as vivid as the Life. In this Case d is equal to f, and substituting d for f in the Equation, we shall have $pdre = ddr + ddp - dpe - pre$, and dividing all by $d.pre = dr + de - pre$, that is, $\frac{2pre}{r+e} = d$; but if the two Convexities be of the same Sphere so as $r = e$, then will the distance be $= pr$; that is, if the *Lens* be Glass $= 2r$, so that if an Object be placed at the Diameter of the Sphere distant, in this Case the *Focus* will be as far within as the Object is

Digitized by Google

without, and the *Species* represented thereby will be as big as the Life; but if it were a *Plano-Convex*, the same distance will be $= 2\,p\,r$, or in Glass to four times the *Radius* of the Convexity; but of this Method I may entertain the Curious at some other Time, and shew how to magnifie or diminish an Object in any proportion assign'd, (which yet will be obvious enough from what is here delivered) as likewise how to erect the Object which in this Method is represented inverted.

A second Use is to find what Convexity or Concavity is required, to make a vastly distant Object be represented at a given *Focus*, after the one Surface of the *Lens* is formed; which is but a Corallary of our Theorem for finding e, having p, d, r and f given; for d being infinite, that Rule becomes $\frac{r\,f}{p\,r-f} = e$, that is in Glass $\frac{r\,f}{2\,r-f} = e$, whence if f be be greater than $2\,r$, e becomes Negative, and $\frac{r\,f}{f-2\,r}$ is the *Radius* of the Concave sought.

Those that are wholly to begin with this Dioptrical Science, cannot do better than to read with Attention a late Treatise of Dioptricks, published by *W. Molineux*, Esq; R. S. S. who has at large shewn the Nature of Optick Glasses, and the Construction and Use of Microscopes and Telescopes; and though some nicely Critical have endeavoured to spy Faults, and to traduce the Book; yet having long since examin'd it with Care, I affirm, that if I can judge, it hath but two things that with

any

any Colour may be call'd Faults; the one, an over-careful acknowledgment of every Trifle the Author had receiv'd from others; and the other, that he labours to make easie this curious Subject, so little understood by most, in a manner perhaps too familiar for the *Learned Critick*, and which demonstrates that it was writ *cum animo docendi*, both which require but very little Friendship or good Nature in the Reader, to pass for Vertues in an Author.

But to return to our first Theorem, which accounting for the thickness of the *Lens*, we will here again resume, *viz.*

$$\frac{m\,p\,d\,r\,e - n\,d\,e\,r + n\,p\,r\,e\,r}{m\,d\,r + m\,d\,e - m\,p\,r\,e - m - p\,d\,t + n\,r\,t} = f.$$

And let it be required to find the *Focus* where a whole Sphere will collect the Beams proceeding from an Object at the distance d: Here t is equal to $2\,r$, and $r = e$. And after due Reduction, the Theorem will stand thus, $\frac{m\,p\,d\,r - 2\,n\,d\,r + 2\,n\,p\,r\,r}{2\,n\,d + 2\,n\,r - m\,p\,r} = f$; but if d be Infinite, it is contracted to $\frac{m\,p\,r}{2\,n} - r = \frac{2\,n - m}{2\,m - 2\,n}\,r = f$, wherefore a Sphere of Glass collects the Sun-Beams at half the Semi-diameter of the Sphere without it, and a Sphere of Water at a whole Semi-diameter. But if the *Ratio* of Refraction m to n be as 2 to 1, the *Focus* falls on the opposite Surface of the Sphere; but if it be of greater Inequality it falls within. Ano-

Digitized by Google

Another Example shall be when a Hemisphere is exposed to parallel Rays, that is, d and e being infinite, and $t = r$, and after due Reduction the Theorem results $\frac{nn}{mm - mn} r = f$. That is, in Glass it is at $\frac{3}{2} r$, in Water at $\frac{9}{4} r$; but if the Hemisphere were Diamant, it would collect the Beams at $\frac{4}{3}$ of the *Radius* beyond the Center.

Lastly, As to the Effect of turning the two sides of a *Lens* towards an Object; it is evident, that if the thickness of the *Lens* be very small, so as that you neglect it, or account $t = 0$; then in all Cases the *Focus* of the same *Lens*, to whatsoever Beams, will be the same, without any difference upon the turning the *Lens*: But if you are so curious as to consider the thickness, (which is seldom worth accounting for) in the Case of parallel Rays falling on a *Plano-Convex* of Glass, if the plain side be towards the Object, t does occasion no difference, but the focal distance $f = 2r$. But when the Convex-side is towards the Object, it is contracted to $2r - \frac{1}{3} t$, so that the *Focus* is nearer by $\frac{1}{3} t$. If the *Lens* be double Convex, the difference is less; if a *Meniscus*, greater. If the Convexity on both sides be equal, the focal length is about $\frac{1}{6} t$ shorter than when $t = 0$. In a *Meniscus* the Concave-side towards the Object increases the focal Length, but the Convex towards the Object diminishes it. A General Rule for the difference arising on turning the *Lens*, where the *Focus* is Affirmative, is this $\frac{2rt - 2\varrho t}{3r - 3\varrho + t}$, for double Convexes of differing Spheres. But for

Menisci

Digitized by Google

Digitized by Google

Menisci the same difference becomes $\frac{2rt+2\varrho t}{3r-3\varrho+t}$; of which I need give no other Demonstration, but that by a due Reduction it will so follow from what is premised, as will the Theorems for all sorts of Problems relating to the *Foci* of Optick Glasses.

FINIS.

ADVERTISEMENT.

For the Advancement of Natural Philosophy and Astronomy,

As well as for the Benefit of all such Curious and Inquisitive Gentlemen, as are willing to lay the best and surest Foundation for all useful Knowledge.

There is provided a convenient large Room furnished with all sorts of Instruments; as Engines for rarefying and condensing Air, with all their Appurtenences, according to the Improvement made by Mr. *Hauksby*, with Utensils for making Hydrostatical Experiments. Telescopes of a convenient Length, with good Micrometers adapted to them: Also Quadrants for making Celestial Observations, and good Movements for measuring of Time.

Microscopes of the best sort, both single and double, with Prisms of several sizes for illustrating

Digitized by Google

illustrating the New Doctrine of Light and Colours.

Where a Course of Natural and Experimental Philosophy and Astronomy will begin in *Michaelmas-Term* next, and continue weekly till the whole be done. By *James Hodgson*, F. R. S.

And towards the defraying and compensating so chargeable and laborious an Undertaking, it is proposed, That every Gentleman that intends to benefit by it, shall pay Two Guinea's; one at the time of Subscription, the other as shall be judged most convenient.

Proposals more at large, and the Engines for rarefying and condensing Air, with the Utensils for making the Hydrostatical Experiments, may be seen at Mr. *Hauksby*'s, in *Gilt-spur-street* without *Newgate*, where Subscriptions are taken in.

A New Pair of Globes, 12 Inches in Diameter; the Terrestrial is according to the newest Discoveries and accurate Observations that have been made, adorned with an useful View of the General and Coasting Trade Winds, Monsoons, &c.

The Celestial is according to the Catalogue of that Celebrated Astronomer *J. Hevelius*, Consul of *Dantzick*; its Constellations are curiously engraven, and the Magnitude of the Stars are easily distinguished, with 16 new Constellations never before printed upon any Globe. Sold by *John Senex* in *Hemlock-Court*, near *Temple-Bar*, and *Charles Price*, next the *Fleece-Tavern* in *Cornhill*.

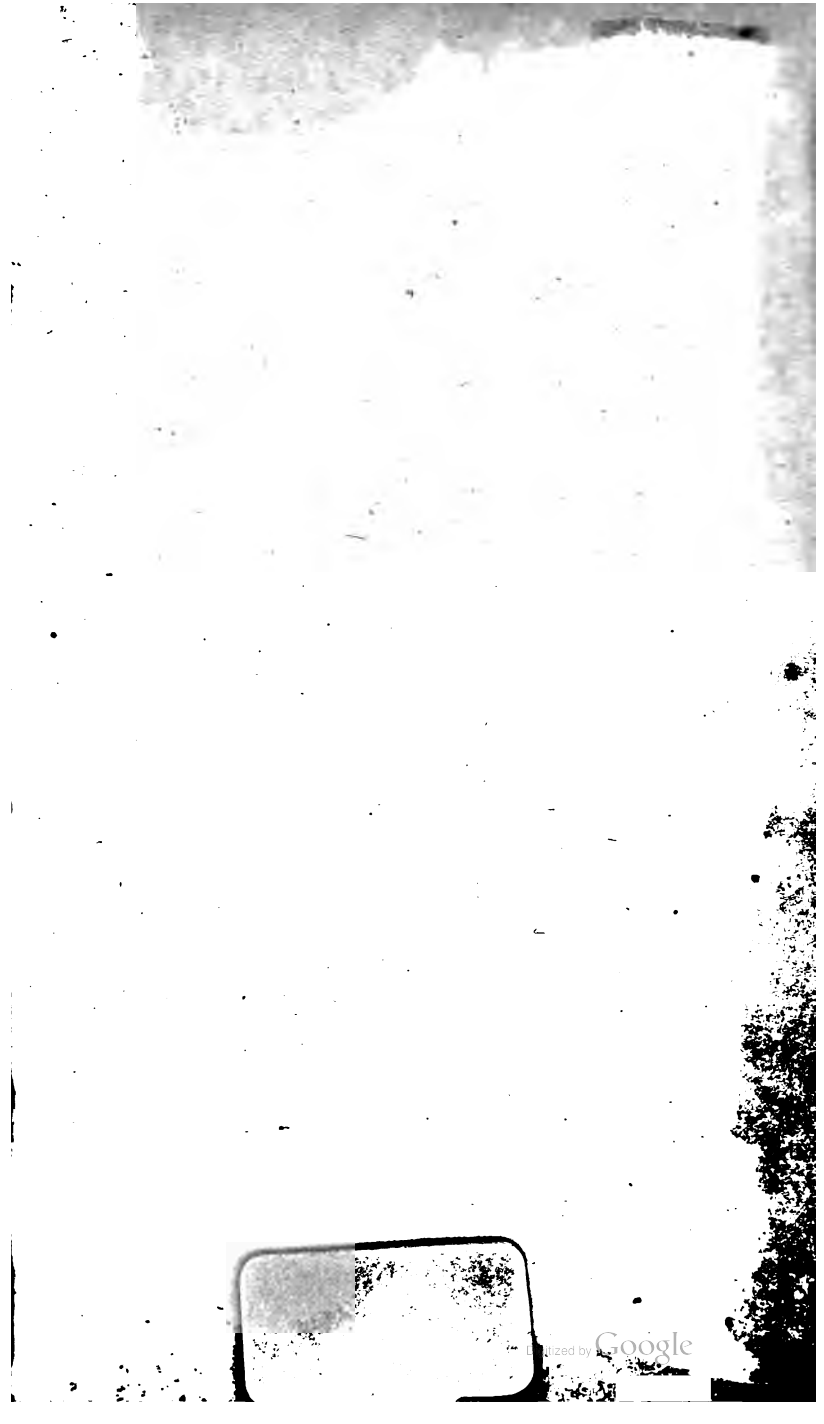
Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google

Digitized by Google


Digitized by Google

Digitized by Google